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Energy Aware Algorithms for managing Wireless Sensor Networks

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Energy Aware Algorithms for managing Wireless Sensor Networks

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While the majority of the current Wireless Sensor Networks (WSNs) research has prioritized either the coverage of the monitored area or the energy efficiency of the network, it is clear that their relationship must be further studied in order to find optimal solutions that balance the two factors. Higher degrees of redundancy can be attained by increasing the number of active sensors monitoring a given area which results in better performance. However, this in turn increases the energy being consumed. In our research, we focus on attaining a solution that considers several optimization parameters such as the percentage of coverage, quality of coverage and energy consumption. The problem is modeled using a bipartite graph and employs an evolutionary algorithm to handle the activation and deactivation of the sensors. An accelerated version of the algorithm is also presented; this algorithm attempts to cleverly mutate the string being considered after analyzing the desired output conditions and performs a calculated crossover depending on the fitness of the parent strings. This results in a quicker convergence and a considerable reduction in the search time for attaining the desired solutions. Proficient cluster formation in wireless sensor networks reduces the total energy consumed by the network and prolongs the life of the network. There are various clustering approaches proposed, depending on the application and the objective to be attained. There are situations in which sensors are randomly dispersed over the area to be monitored. In our resarch, we also propose a solution for such senarios using heterogeneous networks where a network has to self-organize itself depending on the physical locations of sensors, cluster heads etc. The problem is modeled using a multi-stage graph and employs combinatorial algorithms to determine which cluster head a particular sensor would report to and which sink node a cluster head would report to. The solution proposed provides flexibility so that it can be applied to any network irrespective of density of resources deployed in the network. Finally we try to analyze how the modification of the sequence of execution of the two methods modifies the results. We also attempt to diagnose the reasons responsible for it and conclude by highlighting the advantages of each of the sequence.

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Chapter I - Introduction

Many applications in diverse environments make use of smart environments. Smart environments have redefined many applications in industries, homes, transportation, automation and various utilities. Smart environments rely on sensory data that comes from the real world. It is very important to have an organized system that detects the needed information from the surroundings and is aware about its internal workings. The primary challenges dealt by such systems are detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information obtained, formulating meaningful outputs and performing decision making and alarm functions. All the above mentioned problems can be handled by distributed wireless sensor network which provide the needed functionality. Wireless sensor networks commonly use the approach of either randomly or strategically distributing the sensors over the region to be monitored. The sensors report the data, which reflects the condition they sense to the base station. The base station is controlled by the base station controller, it formats the data in the required format and sends it to the data management center which keeps a record of the data and uses the data to identify the status of the monitored area. The complexity involved in a wireless sensor network can be expressed in a broad way as shown in figure 1.1.

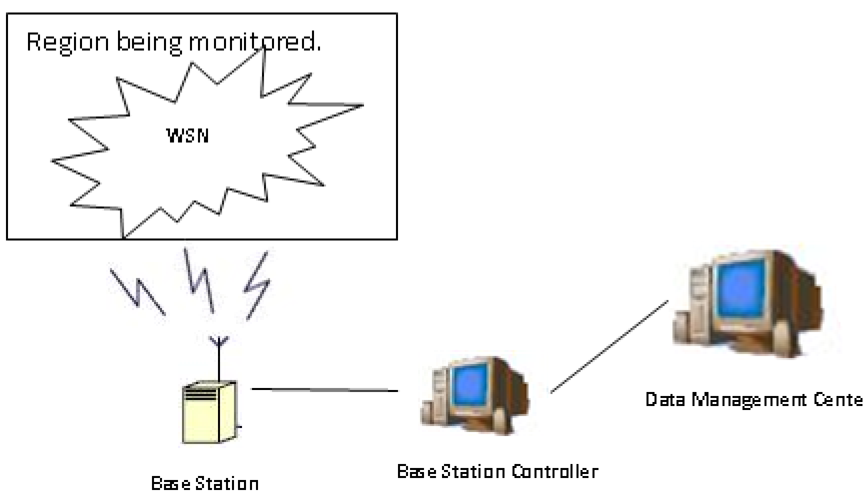


Figure 1.1: Overview of wireless sensor network.

Study of wireless sensor networks is both very broad and challenging as it needs a study from various different disciplines like microelectronics, micromechanics, integrated optics, communication, networks etc. Researchers dealing with wireless sensor networks cover a huge range of topics like deploying of sensors, efficiently covering the monitored area, network architecture, frameworks, network topology, security routing protocols, data fusing, information managing, dynamic resource management, corresponding and task distributing, communicating model, network energy limiting and network life, quality of server, mobile nodes and network security etc. Any wireless sensor network consists of a large number of sensors; a wireless sensor is a sensing module which has one or more sensor transceiver nodes. Due to the recent hardware advancements the cost of manufacturing a sensor has reduced a lot making it feasible to produce them in huge quantities. There have also been advancements in the way the wireless sensor networks communicate and different wireless sensor networks could use different technologies and transmission techniques like Wi-Fi, Bluetooth, zigbee or CDMA/GSM. All the devices that are used in the wireless sensor networks need to have enhanced technology which facilitates them to work efficiently both collaboratively and independently. The devices or system are built on specific technology which can increase the ease and safety with which the task can be performed. The technology needs to be primarily adaptive which helps the system or device to be modified easily according to the requirements of the business it is deployed in. With this property, the system is bound to perform more efficiently without many complexities. The devices built also need to have the property of being assistive which helps the devices to better perform for the situations for which they are built for.

The primary role of sensors is to track and monitor some physical activity in a number of different applications. To name a few applications, sensors are widely used in are environmental monitoring, seismic detection, military surveillance, inventory tracking and smart spaces. Individual sensors form the wireless sensor network which aims at monitoring the region of interest in a smart and predictable way, to attain this sensor have to work in collaboration to achieve some task. The importance of wireless sensor networks cannot be ignored due to its growing importance in various fields, few of the primary applications are as listed below:

1. Military applications:

Sensor networks have a very important role to play in the military sensing. Wireless sensor network form the integral part of various operations like surveillance, communications, control and computing. With respect to the battle field, sensors networks having properties like rapid deployment, self-organization and fault tolerance are desired. Sensors could play a vital role in any of the following conditions: monitoring forces, equipment and ammunitions, battlefield surveillance or battle damage assessment.

2. Environmental applications:

The role of sensor networks in diverse fields like habitat monitoring, agriculture research, fire detection and traffic control continues to increase. These days, sensors are easily deployed to remote and inaccessible places. The deployment and maintenance of these sensors should be easy and scalable. The individual nodes that make the wireless sensor network sense the changes and report them to other nodes of the similar or superior built. A large number of sensors are deployed over large areas to monitor the impacts of various factors, support risk assessment and environmental sustainability.

3. Health applications:

Wireless sensor networks carry the promise of improving the quality of care across a wide range of services. WSNs can be used to notify the early deterioration of the health of patients being monitored and enhance the responder's capability to respond faster in cases of emergency. The quality of life of the elderly can be improved by smart environments. Using of wireless sensor networks gives a large scope for studying the human behavior and various chronic diseases. WSNs also have helped in drug administration and the reaction it has by tracking the muscle activity.

4. Home applications:

Sensors are widely used for detecting motion to power on or off various devices. Another common use of sensors is for smoke detection other than these common uses, wireless sensor network make it feasible to have smart homes, which aim at delivering systems that should be responsive, interconnected and intelligent. Sensors are capable of providing helpful contextual information and with the recent developments it is possible to have high level recognition of a resident's interleaved activities. These advances have plenty of applications from bridge structure monitoring to context aware health care.

1.1 Network lifetime of WSNs

Wireless sensor networks continue to find increasing demand in a variety of different application domains as discussed. Considering the limited resources available to a WSN, the demand for building energy efficient wireless sensor networks for various different applications having different requirements continues to be the primary challenge faced by the researchers working on wireless sensor networks. The primary resources that a wireless sensor network needs can be roughly stated as energy, processing capacity and storage capability. Apart from the these limitations, depending on the task a wireless sensor network could be subjected to other limitations as well for instance varying density of sensors could be deployed which could play a major role in determining the behavior of the network; the environmental conditions also increase the challenges faced by the WSNs. Since wireless sensor networks are composed of sensors which are made of nodes that are battery operated and are expected to work for a long period without any attendance, energy efficiency is a key parameter in WSNs. Also since they operate in a resource constrained environment, the network lifetime determines the efficiency of the network because a network can fulfill its purpose only as long as it is alive.

The accurate modeling of the lifetime of WSNs is needed as the network lifetime can be viewed in different ways depending on the purpose for which the wireless sensor network is deployed for; one such view could be the lifetime of the network is the lifetime of the single nodes that make up the network. The lifetime of a sensor node primarily depends on two factors: how much energy it consumes overtime and how much energy is available for consumption. Depending on the importance of the area being monitored, the number of sensors that should be turned on should be determined. Some regions being monitored may be of high importance and could require a high amount of redundancy for monitoring while other regions may work with as few active sensors as possible. As it is almost impossible to recharge or replace the batteries of the sensors in most of the cases.

The lifetime of a sensor network is defined in different ways; various different literatures have used different definitions for the lifetime of a network [37]. Few of the different ways existing to define the life of the network are as follows:

1. Network lifetime based on number of nodes alive:

If there are n nodes monitoring certain region, as soon as a single node fails the network lifetime will end. The lifetime calculated by this metric will be too short for most practical purposes. A slight modification of this criterion is a network is said to be alive if a certain percentage of nodes in it are alive. Once the number of nodes fall below the given threshold the network is declared to be dead. The modified categorization still lacks accuracy as sensors at some key positions could fail but the total number of active sensors could still be above the threshold.

2. Network lifetime based on sensor coverage:

The network lifetime can be also defined as the time for which the region of interest is covered by the sensor nodes. Coverage can be defined in various ways depending either according to the composition of the region of interest or the redundancy of coverage desired. The coverage redundancy in turn can be defined in two ways, first requires that a given percent of the region of interest is covered by at least one sensor, the second approach aims at having each point covered by some specific number of sensors.

3. Network lifetime based on connectivity:

Network lifetime is also determined based on the connectivity of the network. The main job of any network is the ability to transmit data to a given destination. Different researchers have introduced different sub categories in this category to define the lifetime of the network for instance the minimum time when either the percentage of alive nodes or the size of the largest connected component of the network drops below a threshold level or the network lifetime has also be defined according to the total number of packets that reach the sink. The results in this type of classification heavily depend on the algorithms being used.

4. Network lifetime based on sensor coverage and connectivity:

Many authors in their research combine the coverage based and connectivity metrics. The network lifetime is defined as the time in which either the coverage or connectivity drops below a defined threshold. In other words it can be said as the time for which the network can perform the sensing functions and transmit the data to the sink. Most practical applications use different variations of this classification for determining the lifetime of their network.

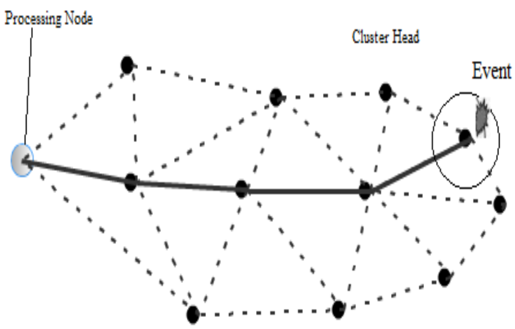


Figure 1.2a: Data is reported to the processing node in multiple hops.

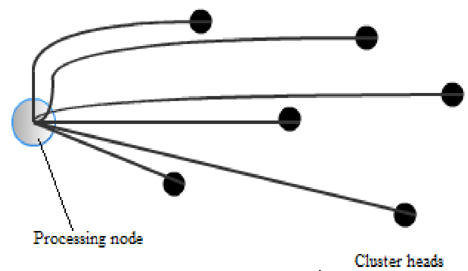


Figure 1.2b: Data is directly reported to the processing node.

5. Network lifetime based on application quality of service requirements:

There are specific applications that have specific needs. A network is said to be alive as long as it satisfies those specific needs.

Depending on the need of the application for which the sensor network is deployed, the appropriate definition for the lifetime of the network is chosen. In any case, sensors are very much limited due to the energy constraints of the batteries and it is expected of every network that its network lifetime should be as long as possible. Clustering has been one of the effective approaches used to improve the network lifetime. The most common type of clustering employed by wireless networks has sensors grouped into clusters; every cluster has a coordinator to which all the sensors of the cluster report to usually referred to as cluster head. Cluster heads then report the collected data to the sink nodes either in single or in multiple hops. Clustering is done in both homogeneous and heterogeneous networks. The heterogeneous networks have some superior nodes which permanently play the role of cluster heads. In homogeneous networks, the role of cluster head is rotated among the sensor nodes with all the sensors in the cluster periodically playing the role of the cluster head. The data collected by the cluster heads is either directly reported to the sink node or is reported to it in multiple hops as shown in figure 1.2.

For the efficient working of the wireless sensor networks, a mechanism which maximizes the network lifetime making sure that the required area is properly monitored and the desired connectivity is obtained. To increase the lifetime of any network, irrespective of the way the lifetime of the network is defined the energy must be conserved as much as possible making energy conservation in WSNs critical and one of the hot research topics. Energy conservation in wireless sensor networks could be usually dealt on one of the following levels [4]:

1. The sensors should be efficiently scheduled between sleep and active modes.
2. The processes of routing, clustering and data aggregation should be made as energy efficient as possible.
3. Appropriate transmission power should be utilized making sure that there is the required connectivity in the network.
4. The data that is transmitted should be compressed to reduce the amount of energy needed for transmission.
5. The channel access and packet retransmission must be efficiently utilized on the data link layer.

1.2 Different challenges faced by WSNs

Wireless sensor networks also have certain unavoidable tradeoffs, the nodes that make up the wireless sensor network are battery powered and they have to use the energy provided by them for sensing, processing and communication. The major challenges faced by any WSN can be listed as follows [35, 36]:

1. Interoperability and Interference:

With the increase in the number of wireless devices used today, there is a need to avoid or limit the interference caused among different sensors and other RF devices. It is needed to provide interoperability between the devices making up the network and help support the relationship among those devices. There could also be interference due to physical devices such as a wall etc. Hence, there is a strong need to reduce the undesired emissions.

2. Real time data acquisition and processing:

Efficient communication and processing the data over the network are one of the major needs of any kind of network. For wireless networks various techniques like event ordering, time stamping, synchronization and quick response to emergency are employed for these types of issues.

3. Reliability and robustness:

Wireless sensor networks are not expected to be maintained regularly due to a number of reasons like cheap hardware, inaccessibility etc. making it very important that the devices must be operated with some efficient algorithms which provide reliable data to analyze a scenario or track an activity.

4. Limited Battery:

Keeping in mind the conditions in which a sensor has to accomplish its tasks, it should be designed such that it has low power consumption. The process of sensing, processing and communication should take as minimum energy as possible. Many sensors have lithium batteries instead of AA batteries as the latter suffer from physical degradation and leakage currents. Lithium batteries also have the advantage of being thin due to which the size of the battery is minimized which further helps in minimizing the size of the sensor. Since the battery is limited, the sensors should quickly and effectively enter and leave the sleep state.

5. Integrated Circuits:

Most of the applications use sensors that have their integrated circuits custom designed for the application for which it is going to be deployed for. The size of the integrated circuits has also been reducing which have contributed to reduction of the size of the sensors. A major task in this field is to make that the customized integrated circuits work with the available node voltage supply.

6. Energy conservation:

The nodes in the sensor network face the major challenge of having limited computational and communication capabilities. This increases the need for having efficient algorithms which appropriately turn the desired sensors on or off depending on the requirement of the situation. In any case the more energy aware any network is the longer will be the network lifetime and such networks will serve their purpose for a longer time.

7. Wireless communication:

One of the highest energy consuming component of a sensor is the RF communication, as a result there is major emphasis on having energy efficient communication strategies to help maximize the lifetime of the nodes. There has been extensive research on the effect of multipath fading and noise on signal detection, information fusion, medium access control protocols and routing protocols.

8. Routing:

The wireless sensor networks consist of networks which are usually densely populated by the sensors. In most of the cases, the wireless sensor network is responsible for establishing an ad hoc network to forward and communicate data. They must then carry out the task of routing information. The protocols used for routing must be robust as link failure due to battery energy depletion or failure of the hardware of any node could cause the loss of data. According to the different routing protocols, radio irregularity has a significant impact on the efficiency of path reversal and neighbor discovering algorithms.

9. Data Management:

The data of interest must be saved and there should be a facility for the end user to query and accordingly get the data of interest. This is usually handled with an embedded real time database. As the data collected is sensitive, there is also a need that the privacy of the person monitoring the data is preserved. There should also be facilities of accessing the data during emergency times as required.

10. Distributed Signal Processing:

In Wireless sensor networks the task of efficiently coordinating signal processing is gaining high importance. The task of distributed signal processing arises primarily due to the limited processing capacity of the sensor nodes and the effect of energy and bandwidth constraints. The sensor nodes cannot share raw data as this puts a load on the bandwidth which in turn puts a load on the battery of the nodes. To avoid this, most sensors perform basic local signal processing and data compression. Since the sensor nodes could die due to battery depletion or failure of the nodes, the design of distributed signal processing algorithm which is robust and unaffected by the network topology is a challenging task. Some of the common challenges faced by the network is time synchronization.

11. Security:

A wireless sensor network could be deployed in environments that are hostile and due to the distributed nature of the network it is more vulnerable to attacks. The term denial of service (DoS) is used for any task that objects the network from doing its primary goal. The security of the wireless sensor networks should be such that it can avoid all unnecessary interferences faced by the system.

1.3 Various scopes of research in WSNs

Wireless sensors have a broad scope for research. There are various fields in which research can be done. Some of the fields in which researchers have put efforts are as follows:

1. Mobility:

Mobility could be considered as a series of topology changes. With every node movement some network links break up and others get established resulting in the change in the topology. A similar effect can be observed with the failure of any node. Another reason why researchers are exploring the mobility of sensors is because in practical applications, mobility is very useful in different situations like in warfare where sensors are just distributed over the area that is to be monitored or in places like glacier where it is not feasible to plant sensors and they are randomly dispersed. There could also be cases where any sensor is randomly damaged causing the topology to fail.

2. Heterogeneity:

A network is a heterogeneous network if it is composed of more than one type of node. One of the most common type of heterogeneity found in most of the literatures is dividing the sensor nodes on the basis of their battery power, few of the sensors are assumed to have a larger energy for their disposal. This concept is usually used in networks where clustering is involved with the superior sensor playing the role of a cluster head. A few other types of heterogeneity can be as follows: some nodes could have to send larger amount of data, some sensors could have to play a superior role in covering the monitored area having better sensing ranges, sensors having varying transmission ranges.

3. Quality of service:

Different applications have different demands from the wireless sensor network and the QoS could be defined in different ways according to the requirement. Most commonly the QoS measures include the delay in response and transmission times, the throughput and bandwidth, the loss and error rates and the resource consumption. The QoS requirements of a sensor network could be different the traditional measures.

4. Deployment of sensor nodes:

The deployment of sensor nodes could either be done with a calculated approach, by deploying sensors at chosen spots in a geographic area or they can be randomly distributed over the area to be monitored. In most of the applications it is a one-time task but the way the sensor is deployed varies. Some applications have the deployment done in a hierarchical order where a particular type of sensors are deployed first and the other type of sensors are deployed later. In some applications the deployment sensors is done hierarchically in order to attain certain requirement for instance the coverage area may need to be increased gradually due to which sensors are deployed in sessions. During deployment, the major factors that could affect the working of wireless sensor network is the sensor node density and increase in the degree of the network dynamics.

5. Cost and size of the wireless node:

The cost and size of the nodes in case of wireless sensor networks are not independent of each other. The sensor nodes in a wireless sensor network are independent autonomous devices which makes the resources available to the devices very much dependent on the size of the nodes. The size of the sensor determines the hardware and software that can be made available to the sensors which in turn effects the computation, energy storage and communication capacity of the sensor. The advantage of smaller sensors is that it can be more conveniently deployed. Depending on the application the sensor is used for an appropriate choice should be made, deciding what sensor size is to be used.

6. Infrastructure of the network:

The network scheme can be of two types. First, infrastructure based network in which all the sensor nodes communicate with the base station and the base station then responds back to the individual sensor nodes and second is the ad-hoc based network in which sensors communicate among each other acting as routers and the data is then finally reported to the base station over multiple hops. The deployment and working cost of the infrastructure based network usually turns out to be more expensive than that of ad-hoc based networks. A lot of models have been suggested which are a combination of both infrastructure based and ad-hoc based networks.

7. Network Coverage:

The coverage area of the network is dependent on the physical locations of the sensors and the coverage range of the sensors. The area of interest can be more effectively monitored if the network is denser and better data redundancy can be obtained. However denser networks also cause more energy to be consumed. The redundant nodes could be turned off to save power, appropriate algorithms should be employed which make sure that the required coverage is attained with maximum energy saving.

8. Power Management:

In most of the applications where wireless sensor networks are used, they are situated in geographically distributed environments. Moreover, changing the batteries of the sensors frequently could be burdensome. This makes the power generation, power conservation and power management very crucial factors in extending the lifespan of the networks. The major power consumption occurs in the process of RF communication as the required transmission power is directly proportional to the square of the distance between the source and the destination. Depending on the application and its needs, appropriate energy must be spent with the desired requirement being achieved.

9. Lifetime of the sensor network:

A network is said to be alive either until it satisfies certain conditions or it is efficiently performing the task for which it is deployed. As replacement of sensors is not the feasible option, the wireless sensor network must be robust and energy efficient. From the above discussions it can be concluded that lifetime of the sensors plays a key role and has a high impact on the designing techniques. Depending on the application, the lifetime of the network has a huge range of variation. It can be a few minutes or even several years.

1.4 Proposed research and Motivation

Wireless sensor networks are used in a variety of different applications. Different applications have different challenges for instance some applications have abundant energy available and need to have the coverage maximized while other need to maintain a long life of the network so have energy conservation as the priority. In our research we consider the energy consumed for monitoring and the energy consumed for communication. We aim to have adaptable algorithms and execution sequences which depending on the situations could produce varied results so that the requirements of our application are satisfied.

Majority of the researchers target one area of the wireless sensor network and suggest improvements for the same in that department at times the proposed solution could be expensive to the system as a whole. For instance there has been a lot of research done in minimizing the energy consumption of the sensors, increasing the lifespan of the network, self-stabilization and accommodation of various node failures and quality routing of data packets. The WSNs are expected to behave according to the environment they are monitoring. Some applications are very critical and need networks specifically designed for them but this is not true for all. Few applications demand that the sensor networks behave flexibly according to the region they are monitoring. For instance, a wireless sensor network monitoring an area of critical importance should monitor the entire region with a high degree of accuracy, such an application prioritizes the coverage and the quality of coverage over the energy saved. So a model which can control the activation and deactivation of sensor nodes according to what the situation requires is highly desirable. In our research we aim to simulate a wireless sensor network which determines which sensors to keep in an active state for any desired performance. The problem of WSNs flexibly monitoring an area depending on the priority to serve has been addressed in few papers. There has been an attempt to maximize the coverage of the monitored area with as few active sensors as possible by using the mathematical model of Gur game. Flexible monitoring can also be attained by distributed ants algorithm which aims at activating or deactivating sensor nodes using the principle of graph coloring. In different situations the network could have coverage, quality or energy saved as the parameter of prime importance. Hence, we propose a new model for organizing WSNs which focuses on efficient scheduling of sensors between active and inactive states using the evolutionary algorithms; we primarily aim for designing a solution which could be applied on any network irrespective of its size or the application it is being used for. A fitness function for the network is defined based on the percentage of covered area, quality of the coverage and the total energy saved. The algorithm that we use helps in generating a number of possible outcomes for any input case. The fitness functions of all the generated outputs are considered, then the output having the best fitness function is selected, and accordingly the appropriate sensors are turned on or off.

The overall system that we have considered for our research is a heterogeneous system where all nodes do not have the same built, capacities or roles. The system has some nodes that are of superior built and perform the role of permanent cluster heads which collect the data sensed by the other nodes and report the sensed data to the sink nodes. We deal with the issue of clustering in the second part of our problem. Clustering provides network scalability and network topology stability and has energy saving attributes. Due to the various schemes employed in clustering there is reduction in communication overheads and interferences among the sensor nodes. There are various ways in which a clustering scheme can be classified. Clustering schemes are categorized depending on what objective the cluster intends to attain [24, 25]:

- Dominating-Set based clustering
- Low-maintenance clustering
- Mobility-aware clustering
- Energy-efficient clustering
- Load balancing clustering
- Combined based metrics clustering.

The clustering scheme has also been classified according to the cost in some aspect as follows:

- Explicit control message for clustering
- Ripple effect of re-clustering
- Stationary assumption for cluster formation
- Constant computation round and communication (message) complexity.

Cluster heads have a limit of the number of sensor nodes it can manage. If that limit is exceeded the sensor nodes have to communicate to other cluster heads that still have the capacity to receive data from the sensors. It should be made sure that even if sensors do not report to the cluster heads physically located closest to them, the overall communication cost of the system should be kept as minimum as possible. In many practical applications, sensors are randomly distributed over the area to be monitored so many sensors could be located closer to some particular cluster head. The major challenge faced during clustering in such networks is to decide which sensors should and which sensors should not report to the cluster head physically located closest to them. In the second part of our research we propose a new model for distributed clustering for heterogeneous networks which focuses on allocating sensors to cluster heads such that the total communication cost for the entire system is minimum. The suggested model also provides flexibility by which the density of networks and number of resource handling capacity of a device can be altered.

Chapter II – Previous Work

2.1 Introduction

Wireless sensor networks are used extensively in a variety of different applications encouraging researchers to propose various protocols and algorithms for its smooth and efficient operation. In WSNs sensors could either be randomly or deterministically distributed over the region of interest. They coordinate with each other to successfully transmit the sensed data to the base stations. Initially most of the research on WSNs focused on the interconnection between the various nodes in the network at the various OSI layers. Such systems usually lacked a central processing node to which the nodes reported to. Over time a number of solutions have been proposed such that the WSNs can be used in a variety of applications. Most solutions implement the idea of self-forming, self-configuration and self-organization so that depending on different scenarios a feasible output is provided.

How does self-organization help WSNs? WSNs need self-organization; they need an energy efficient sensor management protocol which assures that depending on the requirement of the situation minimum sensors are used to accomplish the required task. Self-organized systems can be introduced in many different fields. Self-organized systems can be defined as systems that organize themselves by evolving without the help of any external parameter. In such systems a pattern at the global level emerges due to interactions among the lower level components of the system. The rules that decide the nature of interaction among the lower level components are implemented using the local information only. Self-organized systems are used in a number of fields to name a few it is used in networks, scheduling, image processing etc. Examples of self-organization include a wide range of pattern formation in both the physical and biological systems like sand grains assembling into rippled dunes and images forming some particular pattern based on the color, texture and orientation. Pattern is usually used to refer how objects are arranged in a particular arrangement over time.

According to our study the final goal of almost every research is to increase the network lifetime of the wireless sensor network. A network is said to be able to fulfill its desired purpose as long as it is alive due to which the network lifetime is given such prime importance. Depending on the task the WSN attempts to accomplish, the network lifetime definition could vary. However, the network lifetime is primarily defined by parameters like availability of nodes, coverage provided by the network and the connectivity between the various devices deployed in the network. A few research papers also consider the QoS as a parameter to define the lifetime of the network. A number of papers have been proposed to increase the lifespan of the network; the algorithms proposed consider the particular definition of lifetime and attempt to maximize it as much as possible. The network lifetime has become a hot research topic primarily due to the reason that recharging or replacement of batteries of the sensors is not feasible in most of the cases. There are various lifetime metrics defined as the network lifetime is discussed and studied from various different viewpoints.

Network lifetime depends strongly on the lifetime of the individual nodes that comprise the network. Irrespective of how a particular network lifetime is defined in the end it comes down to the lifetime of the individual nodes of the network. In order to predict the lifetime of the network, the lifetime of the individual nodes must be predicted accurately. The lifetime of the individual node can be determined by the following parameters:

- Amount of energy available for consumption.
- Amount of energy consumed for proper functioning.

The task of increasing the network lifetime can be brought down to efficiently using the energy available by the network. It is possible to have energy efficient sensor networks by making sure that the sensors that are not needed at any particular time are in an off state. The network should dynamically adapt to device failure or degradation. There could also be cases where the sensors relocate their physical position, the network should adapt to such conditions. Some networks have sensors that also take the responsibility of routing data to the areas of concern, which again leads to energy consumption. Sensor nodes are small devices with limited storage and processing speeds; they organize and collaborate with each other to accomplish a larger processing task. Sensor nodes have radio which can be in one of the following states: transmit, receive, idle or sleep. Power saving techniques is implemented in one of the following categories[4]:

1. Scheduling the wireless nodes between active and inactive states.
2. Controlling transmission power by varying their transmission ranges, to ensure optimal trade-off between energy consumption and connectivity.
3. Energy efficient routing, clustering and data gathering.
4. Saving energy by minimizing the amount of redundant data transmitted.
5. Efficient channel access and packet retransmission protocols on the data link layer.

What is the significance of clustering in WSNs? Clustering has proven to save energy in WSNs. In cluster based WSNs, the sensors report the data to a cluster head which may either by fixed (in case of heterogeneous networks) or may be selected with some parameters (in case of homogeneous networks). There are various clustering schemes and are categorized depending on what objective the cluster intends to attain [23]: Dominating-Set based clustering, low-maintenance clustering, mobility-aware clustering, energy-efficient clustering, load balancing clustering, combined based metrics clustering. The clustering scheme has also been classified according to the cost incurred in some aspects [23] for instance the explicit control message for clustering, ripple effect of re-clustering, stationary assumption for cluster formation, constant computation round and communication (message) complexity. An alternate way to classify clustering specifically in ad-hoc networks are the following [24]: single-hop or multi-hop, location based or non-location based, synchronous or asynchronous (depending on the network topology) and stationary nodes or mobile nodes. All the non-cluster head nodes report the sensed data to the cluster head which in turn forwards the data to the processing node. Clustering helps in saving energy as only the cluster heads are involved in routing and relaying the data. Other advantage of using clustering is it reduces the load on the bandwidth and enables its reuse. However, clustering consume energy in aggregating and routing data. Hence the cost of reporting the sensed data from the sensors to the cluster heads should be kept as minimum as possible. We have studied one such research which tries to prolong the network life using clustering.

2.2 Scope of research in WSNs

WSNs comprise of a number of sensors which form the network. The sensors are deployed in a large number; they are usually cheap and small in size. The sensor nodes should efficiently use the energy they have because they have limited energy supply and low link bandwidths. Sensors also face the challenge of having low processing and memory capabilities. Hence, there are a number of different departments in WSNs which needs improvement and where research can be done. To name a few, research has been done to minimize the energy consumed by the network and increase the lifespan of the entire network, handling network instability due to different physical parameters like node failure, finding best possible route for the data to be transmitted from the nodes to the processing and also on the relocation of sensors in order to attain some desired feature or functionality. The sensors have low processing and memory capabilities; this is another department where the sensors need improvement. Hence, in wireless sensor networks there could be research in various different directions. Prime areas of research for WSNs fall into one of the following areas:

- Reducing the energy consumption by the network and hence increasing the lifespan of the network.
- Handling the various instabilities that could arise in the network due to physical parameters like node failure or lack of adequate communication.
- Having the sensed data efficiently communicated to the processing node through the cheapest route.
- Physical relocation of the sensors over the monitored area such that it is properly covered.

Researchers have focused on various different problems to improve the performance of WSNs. We have listed a few departments and briefed the ideas proposed by the researchers:

1. ***Improve the coverage of the monitored area:***
   a. *Improving coverage by sensor relocation:* In some critical regions sensors cannot be deployed manually for such situations there are algorithms proposed

for the autonomous deployment of mobile sensors over critical target areas. On the basis of locally available information sensors make movement decisions. Such algorithms help improve the coverage of the region of interest and do not use centralized solutions that require prior assignment of physical locations. The authors have proposed a push-pull algorithm which is executed on each individual sensor and depending on the relative positions of the other sensors the particular sensor is relocated [13].

b. *Improving coverage by only using local information:* Authors present a scheme by which the distance between any two neighboring nodes can be estimated using the local information only [9]. Localization of the network is avoided as the authors feel it is error-prone, expensive and not required for coverage algorithm. CCP (configurable coverage protocol) is proposed which takes the distance between two nodes as the input rather than their actual positions. The coverage objective α is taken as input from the user. Given a set of active nodes, the area is divided into a set of non-overlapping triangles. The vertices of these triangles are active nodes. In case new active nodes are to be added they have to be added one at a time. The ratio of area inside the triangle which is not covered to the area of the triangle should be $1 - \alpha$. An additional node is left active for the reason that if the coverage is not attained by the active sensors it can be recalculated by forming new triangles using the new active sensor. For a large WSN, if the coverage object is met locally it is also met globally.

c. *Implementing Gur game algorithm to increase the coverage:* In the Gur game algorithm, the mathematical model of Gur game is used to increase the coverage of the nodes with as minimum active sensor nodes as possible [10]. The Gur game algorithm is a random algorithm which has a key reward function that measures the whole system performance. It tries to attain global optimization using a greedy approach. The higher performance reward functions moves towards feedback value 1. The state of each node changes after each iteration according to the reward function. Every node irrespective of its vote is either rewarded with probability r or penalized with probability 1-r. At any instance if the number of active nodes is n1, then the reward probability is r(n1). For each iteration, the number of active nodes and the number of region covered is found. The reward function used is:

$$f = 0.2 + 0.8\ e^{v}$$

$$\text{where, } v = (-0.002) * (X_t * 100 - 40)^2$$

X_t is the ratio between regions covered and the active sensor nodes.

The greedy approach used by the gur game algorithm could give positive results in small networks but not in large networks.

d. *Implementation of distributed ants algorithm to maximize the coverage:* The distributed ants algorithm, the nodes of the graph represent the sensors and the concept is similar to graph coloring [11]. Initially the sensors are randomly given on or off state, in terms of the graph the ants algorithm starts with a random coloring of the graph. A given number of ants move around the nodes of the graph and change the color of each node according to the local criteria. At a given iteration an ant moves from one node to the other node which has maximum violations (or else it randomly travels to one of the adjacent nodes) and replaces the color of the node with the new color which minimizes the number of violations (or else any color is randomly assigned to it). For any node in the graph, the number of violations is the number of nodes with the same color as that particular node. This is repeated for each ant. The ant moves to the worst adjacent node with certain probability pn and assigns the best possible color with a probability pc. The process is carried out repeatedly by the set of ants until the algorithm converges or an optimal solution is found.

2. ***Find efficient routes with which data could be transmitted:***

a. *Smart packets are made use of for route finding:* The cognitive packet network (CPN) algorithm use smart packets for path discovery [12]. The algorithm basically uses three types of packets for routing. Smart or cognitive packets are used for finding the route for connections. They implement a reinforcement learning-based algorithm with the quality of service goal in mind. The smart packets do not carry any load and are used to find the routes. The reinforcement algorithm is used to determine whether any path is optimal or not. When the smart packet reaches the destination, it generates a reverse packet which stores the reverse route and the measurement collected by the smart packets. According to the data received by a number of reverse packets, a particular path is finalized for sending the data. All the data packets are sent through the optimal path.

b. *Efficient link scheduling:* The wireless network is modeled using a graph. The source and destination are represented using nodes, for any source-destination pair {s_i , tj} the packet is attempted to be scheduled in a link such that the data is efficiently transferred from the source to the destination [41]. Links are represented by the edges that connect the nodes, if the two nodes can communicate there exists a link between them. Consider a directed graph G = (V, E), the nodes of the graph represent the transmitters and receivers and a directed edge (u, v) represents that the data is transmitted from the node u to the node v. A schedule $S = \{S_{e,t}(e \in E, 0 \ \leq t \leq T)\}$ describes the specific times data is moved over the links of the network, where T is the scheduling period and $S_{e,t}$ is the indicator variable defined as:

$$S_{e,t} = \begin{cases} 1 \; if e \; transmits \; successfully \; at \; time \; t \\ \qquad\qquad 0 \; otherwise \end{cases}$$

Time is divided into uniform frames. The algorithm employs a schedule for each edge e in every frame and tries to make sure that every link is exploited equally.

c. *Delaying packet transmission to find efficient path:* A source node broadcasts a multi-path route request (MREQ) in order to find the route from the source to the destination. The next node receiving the MREQ check their own energy value and forward this request after waiting for a time which is inversely proportional to the energy in their nodes. Hence, nodes having more energy forward the MREQ packet faster. Also there is a threshold energy defined and if the energy level of any path falls below it, the path is no longer considered.

3. ***Improving the Quality of Service provided by the network:***
   a. *Having the sensors divided into cover sets:* Consider a wireless sensor network which is deployed to monitor a large region of interest, a sensor has coverage area which is circular having a fixed radius[38] . During each information retrieval operation only a selected set of available nodes collect the data from the field. The subset is such selected that it guarantees to give a desired QoS parameter and covers the whole region that is to be monitored. The problem is initially treated as a coverage problem and is reformulated as following:
   Given any area A and set of sensors {s1,…,sn}, find a set of cover sets {C1,…,Ck} such that:
      - k is maximized
      - for each sensor appearing in the cover sets {C1,…,Ck} the total energy consumed is not more than the initial energy.

It is attempted to increase the cover sets using a greedy approach is proposed to attain the same; the critical subregions are identified and select a sensor to cover it. Similarly this process is repeated for all the subregions until the desired quality is attained.

4. ***Homogeneous WSNs using algorithms to nominate cluster heads:***
   a. *Nomination based on sensor energy level and broadcasting:* The target monitored area is portioned into lots of hexagonal cells based on the local information [40]. Each cell is given a unique id. A sensor in any hexagon can communicate with any sensor in the neighboring cell. To communicate the sensed data to the processing node, the data is passed through multi-hops by communicating with sensors in other cells. The sensors belonging to a cell has its time frame divided into five phases: initial listen phase (when a sensor turns on it will listen for a random timeout period), hello phase(all the nodes will

start broadcasting their energy level to the current cluster head of the cell depending on the), leader selection phase (depending on the individual energies of the nodes, the leader for the next phase is chosen), sleep phase (any cell can communicate with six other neighboring cells in order to avoid collisions and energy wastage the sensors in any cell go to sleep mode once the sensors in neighboring cells go in hello phase except the leader node is turned on for routing purpose), working phase (sensor nodes have their communication component turned off and their sensing component turned on; the data that they sense is passed to the cluster head in the hello phase if it is immediate data it is passed in the working phase itself.).

b. *Nomination based on some user specified quality:* The network in consideration is homogeneous in nature [42]. Each node maintains a table that keeps all information about its neighboring nodes. The sensor keeps information like Neighbor id, residual energy, the distance from the neighbor, state and weight. All the nodes will be in one of the following states depending on the weight of the sensor: ready, cluster head or cluster member. The weights of the sensor are calculated based on the following equation:

$$W = (w1 + Er) + (w2 \times |\, D_n - \delta| \,) + (w3 \times \frac{D_s}{N}) + (w4 \times \frac{D_B}{D})$$

Where, Er → residual energy

D_n → Degree of node

D_s → Sum of distances

D_B → Distance to the base station

N → degree of node

D → diameter of sensor field

w1, w2, w3, w4 are the weight correspondents of the system which are flexible depending on our needs.

δ → number of nodes the cluster head can handle ideally.

A node is chosen to be a cluster head only if its weight is lower than the weight of its neighboring node’s weights. If some cluster head is overloaded and handles more than δ nodes a re-assignment of nodes is done.

2.3 Motivation for our research

After going through many research works, we felt that not many research deal with flexible monitoring of the region of interest. Expressing in detail our opinion about all the research we had gone through was not feasible so as an example we consider two researches in detail – one for attaining efficient coverage and the other for reducing communication cost with clustering.

a) Example of a research done for attaining the desired coverage

In one of the works that we had seen, the authors were aiming to attain the desired coverage of the monitored area. Energy efficiency of the network was considered once the desired coverage was attained. Sensors are useful as long as they communicate the data they sense to the processing nodes [1]. There needs to be some mechanism controlling the power consumption as both sensing of data and transmitting the sensed data consumes energy. The researchers had made attempts to cover the sensed area by organizing the sensors into a maximal number of set covers that are activated successively. Only the sensors that belong to the set which is active can monitor data and transmit the data. The solution was modeled as a maximum set cover problems and design sets that will be active during any phase of time. The authors attempt to solve the sensor coverage problem. The goal is to have each location in the physical space of interest be under the coverage of at least one sensor. With the coverage as the prime factor an attempt is also made to save as much energy as possible. However, we feel that for any particular area that is to be monitored the quality with which the sensors are monitoring the area also is important. With the help of quality, the redundancy with which the data is being monitored increases. According to us, this research also lacks the flexibility with which the area is monitored for instance if sensors are deployed as smoke alarms in normal rooms in cases like this the energy preserved is the prime factor. With the implemented algorithm, the authors will not be able to attain it.

b) Example of a research done for reducing communication cost by clustering

In one of the research works [39], the authors propose uniform energy dissipation of all the sensors in the network to maximize the network life. Uniform energy dissipation can be attained by balancing the energy consumption by the sensor nodes in the network. There are two methods proposed for attaining the same: the first one considers the different transmission radii depending on the distance between the sensor nodes and the cluster heads. The second is a hybrid communication mode in which the sensor nodes could either send the data directly to the cluster head in one-hop with varying transmission radii or the data could be reported to the cluster heads using multi-hop and fixed transmission radii. The sensor network considered is a multi-hop heterogeneous in which during each cycle of gathering data, the sensors perform the data gathering and report the gathered data to the cluster heads. In a multi-hop network, the sensors located closer to the cluster head have more energy drainage as compared to others as they also perform packet relaying. The area around a particular cluster head is divided into subregions accordingly the sensors monitors the subregions and forwards the sensed data to the cluster head. This is as shown in figure 2.1.

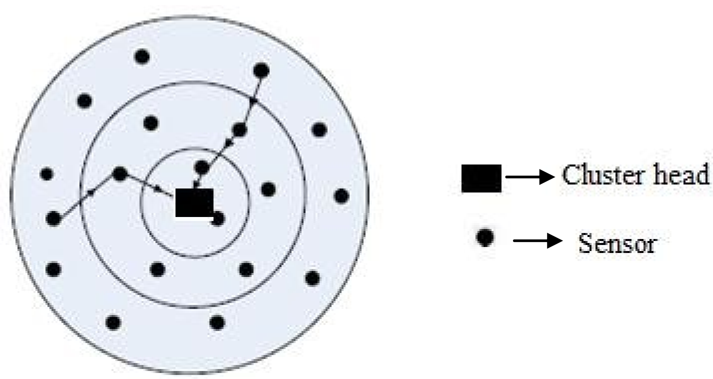


Figure 2.1: Sensors reporting data to CHs in multi-hops

The two methods discussed earlier attempt to manage the uniform energy dissipation. Many research work including this one have the subregions divided in circular shape primarily because the sensor monitor in circular radius so either there could be undesired redundancy while monitoring the region of interest or the sensors could leave some parts of the region of interest unmonitored. Also, if the sensors are randomly dispersed over the area of interest some cluster heads could have more load as compared to the others depending on the density of sensors in its sub-region. In our research we consider the overall cost-effectiveness of the system and accordingly determine which sensor reports to which cluster head. Another factor about the research is that it uses multi-hop routing which would cause the sensors near the cluster heads to drain faster as they have to both monitor as well as pass the data monitored by other sensors to the cluster head. We have considered single-hop routing in our modulation.

In our work what we intend to achieve is a flexible system which can monitor any network irrespective of the size of the network and the density of sensors deployed in the network. The system should be flexible enough to change the priority of the monitored area depending on the application and the needs of the system. We aim at proposing an algorithm in which we determine the status of individual sensors with the help of adaptive genetic algorithms and further extend our algorithm by proposing a combinatorial algorithm which helps in determining which sensors should be clustered with which cluster heads such that the overall communication cost of the system is as low as possible, it is also kept in mind that the number of resources that a cluster head can handle is limited so that the load of further processing and transmitting the data to the sink nodes is done efficiently. Finally we also consider the impact the sequence of execution of these algorithms has on the final output. The next chapters explain all of the mentioned points in greater detail.

Chapter III – Terminology and Problem Description

3.1. Introduction

The WSNs are expected to behave according to the application they are monitoring. For instance, a wireless sensor network monitoring an area of critical importance should monitor the entire region with a high degree of accuracy. So a model which can control the activation and deactivation of the sensor nodes according to what the situation demands is highly desirable. Our research can primarily divided into three major phases. Before we start our explaining our research work, we have explained the basic terms and definitions that are used in the rest of our work:

General definitions used throughout the research:

1. **Wireless Sensor Networks:**
   Wireless sensor networks (WSNs) are a group of spatially dedicated and dispersed sensors. A sensor is node which usually comprises of a radio transmitter/ receiver, a microcontroller and a battery for energy. Sensors are used for monitoring some kind of physical condition like temperature, noise etc in the environment it is deployed in. The WSNs record the readings, process it and then transmit the collected data to the central processing node. Sensors could either be in active or inactive state.
2. **Hierarchical network models:**
   Hierarchical network models are iterative algorithms that are used to create networks which have unique characteristics and high clustering among the nodes. The uniqur characteristics usually replicate some natural characteristic for example some biological characteristic.
3. **Self-Organizing networks:**
   All self-organizing networks implement the activities listed below:
   - Self-configuration: These networks automate the configuration process. All wireless devices either report the sensed data to some other device or to some base station. This is figured out on the self-configuration stage.

- Self-optimization: After the initial allocation of transmission and receiving devices. It is possible to have the same result obtained in a more efficient way. This is obtained in the self-optimization stage.
- Self-healing: In any network, it is possible for some kind of link or device or network failure to occur this failure is accommodated in the network without any loss of data.

4. **Area of interest:**

   This is also called as area monitored or region of interest. WSN monitor some particular region in which the change occurring should be noted. This particular area is called the region of interest. In figure 3.1 WSNs are spread over the region of interest

5. **Subregions:**

   The region of interest is further split into smaller regions called subregions. The subregions may or may not be of the same size and could be defined as per the experiment. In our experiment, the area of interest is equally divided into n subregions. This is as depicted in figure 3.1.

6. **Monitored Area:**

   The part of the region of interest which is under the coverage of an active sensor is called the monitored area or covered area.

7. **Cluster heads:**

   Sensors made up of superior built that manage a set of sensors and primarily have the role of gathering the sensed data from various sensors and reporting it to the sink nodes after processing them.

8. **Sink nodes:**

   All the cluster heads eventually report all the gathered data to the base stations also called as the sink nodes.

9. **Coverage:**

   The region of interest is monitored by the set of active sensors. A particular subregion is said to be covered even if there is one active sensor monitoring that subregion. The percentage of number of subregionsto the total number of subregions gives us the coverage of the WSN.

10. Quality of coverage:

The quality of coverage is used for determining the redundancy with which the region of interest is being monitored. Redundancy can be defined as the duplication of the number of sensors monitoring with the intention of increasing the reliability of the system.

11. Energy:

Energy consumed is the energy required for a certain percentage of total number of sensors to be turned on. Since, the turned off sensors do not consume energy they end up saving it. Hence a network is expected to have a longer lifetime if more number of sensors is turned off.

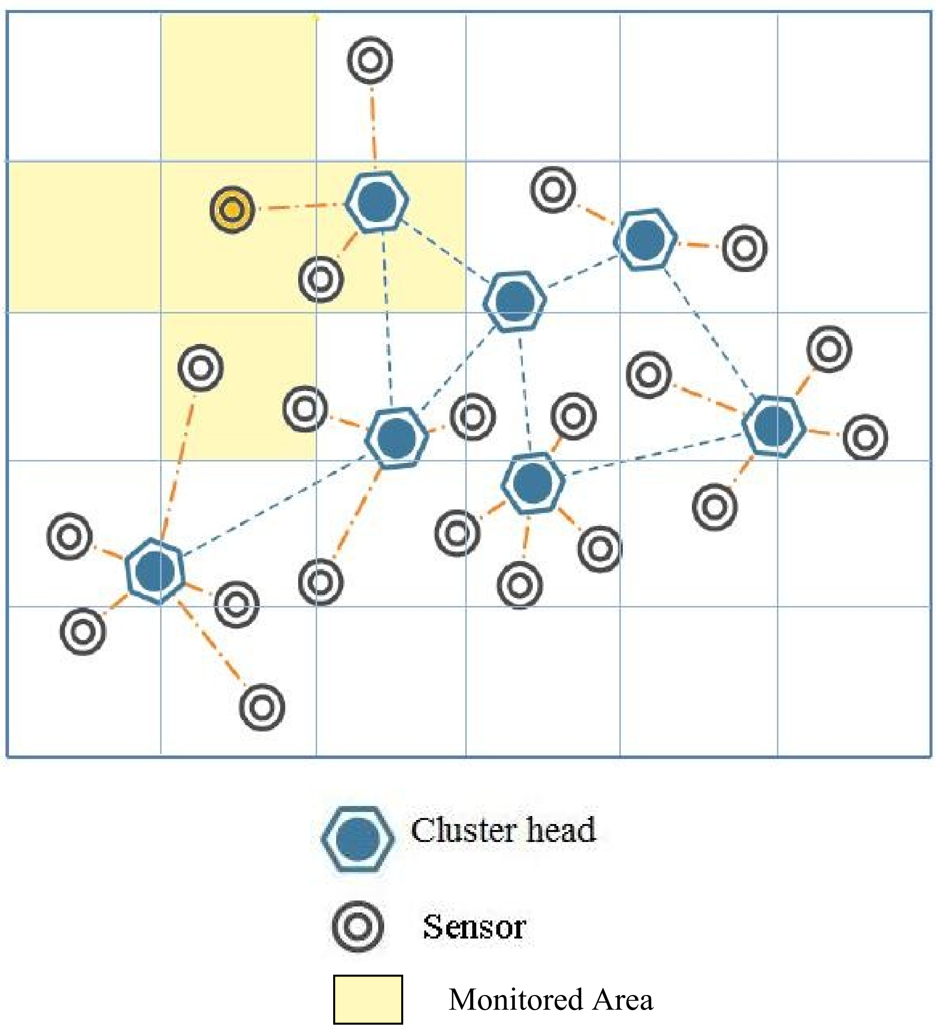


Figure 3.1: Wireless sensor Network monitoring a Region of Interest.

3.2 Problems Addressed

In this first part of our research, we aim to simulate a wireless sensor network with which we could determine which sensors to keep in an active state for any particular desired performance. Various physical factors such as the size of the area monitored, number of sensors monitoring the desired area etc. is considered, and the impact it has on the output produced is observed.

In different situations the network could have coverage, quality or energy saved as the parameter of prime importance. Hence, we propose a new model for organizing WSNs which focuses on efficient scheduling of sensors between active and inactive states using the evolutionary algorithms; we primarily aim for designing a solution which could be applied on any network irrespective of its size or the application it is being used for. A fitness function for the network is defined based on the percentage of covered area, quality of the coverage and the total energy saved. The algorithm that we use helps in generating a number of possible outcomes for any input case. The fitness functions of all the generated outputs are considered, then the output having the best fitness function is selected, and accordingly the appropriate sensors are turned on or off.

In the second part of our research we introduce heterogeneity in the network that we were considering and have sensors, cluster heads and sink nodes deployed in the network. The sensors report to the cluster heads which in turn report to the sink nodes. The main target that we try to achieve is to devise a way by which the active sensors could economically report the sensed data to the processing nodes. Instead of each individual sensor directly reporting to the processing node, the sensors in the WSNs are clustered. Clustering provides network scalability and network topology stability and has energy saving attributes. A clustering scheme is a criterion depending on which the clusters are formed. There are many different clustering schemes which prioritize different properties depending on the different needs of the application and are usually categorized depending on what objective the cluster intends to attain.

Finally in the last part of our work we consider the sequence in which the process is executed as it also plays a significant impact on the results. Most of the research works do not consider this factor. In our work we highlight the impact the execution of sequence of events have and also attempt to determine which conditions require which particular sequence. The rest of the chapter we have introduced the various technical terms that we are using in our research.

3.3. Graph modeling

In simple words a graph is a set of objects called vertices (or nodes) connected by links called edges (or arcs). Graphs are a powerful tool to model any pair wise relation between any object and a particular collection. The object and the collection are represented by nodes and the relations between the objects are represented by edges. The nature of the relation can be implied with weight on the edges. Graph theory has been successfully used in various research areas like data mining, image segmentation, clustering, image capturing, networking etc. Problems like efficient route planning or fault diagnostic is also done successfully with graph theory. Some of the well known graph algorithms are as follows:

- Shortest path algorithm in the network
- Finding a minimum spanning tree.
- Finding graph planarity.
- Algorithms to find adjacency matrices.
- Algorithms to find the connectedness.
- Algorithms for searching an element in a data structure (DFS, BFS).

We have modeled different phases of our research with different graph models. The models that we have used are as stated below:

Bipartite Graphs

A graph is said to be a bipartite graph if its vertices can be divided into two disjoint sets U and V such that every edge of the graph connects a vertex in U to a vertex in V. Bipartite graphs do not have any edges connecting nodes of the same set. Bipartite graph is as shown in figure 3.2. Bipartite graphs are usually represented by $G = (U \cup V, E)$.

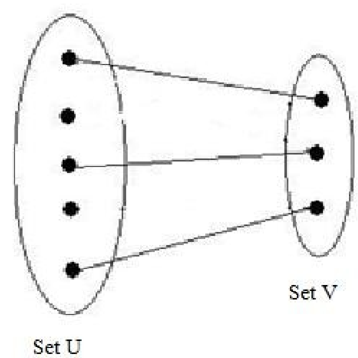


Figure 3.2: Bipartite graph

Multi-Stage Graphs

A graph is said to be a multistage graph if the graph can be partitioned into a set of vertices such that an edge can be drawn from a node in one set to a node in the next set only. No edges can be drawn between nodes of the same set or the nodes belonging to non-consecutive sets. A multi-stage graph is as shown in figure 3.3. Multistage graphs are usually represented by $G = (U1 \cup U2 \cup U3,\ E1 \cup E2)$.

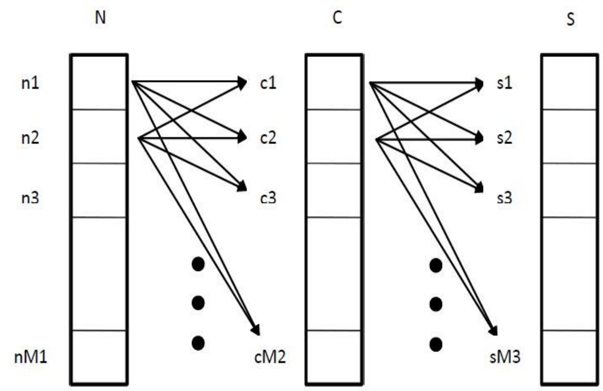


Figure 3.3: Multistage graph.

3.4 Algorithms

In our research, we report results obtained by implementing two algorithms. The first algorithm is based on the evolutionary algorithms and the second one is based on the combinatorial algorithms. Both the algorithms briefed below:

1. Evolutionary Algorithms

Evolutionary algorithms are used as a search heuristic; it uses a process which is very similar to the natural evolution process. In this a population of strings which is also termed as chromosomes or genomes encodes each other to evolve to a better solution. The state of the strings is represented by 1s and 0s in most of the cases but there are variations of the same. The evolution starts randomly in the search space and evolves over generations with each generation expected to be healthier than the previous one. There could be different termination points for the algorithm depending on the purpose for which it is being used for instance in some cases it terminates when no better solution is found, in other cases it terminates when certain number of generations have occurred or even if after certain satisfactory fitness level has been attained.

A fitness function is problem dependent and usually defined over the genetic representation and represents the quality of any individual string. The main operations that occur in the evolutionary algorithms are as follows:

i. *Initialization*: Usually many individual solutions are randomly generated to form the initial population. Randomness is introduced so that the search space could be better explored. The population size could vary according to the problem for which it is being used for.

ii. *Mutation*: Mutation is a genetic operation which alters the value of one or more genes in a chromosome. The mutation could entirely alter the value as compared to its previous value. The number of genes which mutation can modify depends on the probability. Usually, the probability is not kept very high.

iii. *Crossover*: Crossover is a genetic operator which varies the offspring depending on the nature of parents. Two parent strings are given as input and the offspring generated has certain percentage of one parent and the remaining percentage of the other parent.

iv. *Selection*: During each successive generation, a certain percentage of the existing population is further selected for creating the future generations. The population that is selected is usually selected on the basis of their fitness level. If the healthier strings are selected for further operations it is expected that the new generations could be even healthier.

2. Combinatorial Algorithms

Combinatorial algorithms are used for optimizing and they aim for finding an optimal solution from a finite set of objects. These algorithms do not have exhaustive search. These algorithms are frequently used to solve instances of assignment problems which belong to the class of matching algorithms. Usually they are applied in cases where there are two different sets and elements of one set have to be matched to the elements of the other set such that the sum of certain quantities could be maximized. Usually the quantities are either time or cost associated with one entity being executed by the other. Also, each entity of one set can be matched only to one other entity in the other set. The outcome that is expected from the algorithm is an allocation such that the sum of the costs of the individual elements is as high as possible. This concept can be better explained with the help of the example given below:

Consider two people Jack and Tom who have to complete task A & B. The efficiency of the individuals to perform the task is as shown in the matrix in the figure 3.4. If it is to be decided who will perform which task the combinatorial algorithm is used. From the figure it can be clearly interpreted that Jack should do task A and Tom should do task B in order to maximize the efficiency.

	Task A	Task B
Jack	100	20
Tom	50	85

Figure 3.4: Figure depicting efficiency of individuals on particular tasks.

Chapter IV - Evolutionary Approach

The majority of the current Wireless Sensor Networks (WSNs) research have prioritized either the coverage of the monitored area or the energy efficiency of the network, it is clear that their relationship must be further studied in order to find optimal solutions that balance the two factors. Higher degrees of redundancy can be attained by increasing the number of active sensors monitoring a given area which results in better performance. However, this in turn increases the energy being consumed. In this chapter, we focus on attaining a solution that considers several optimization parameters such as the percentage of coverage, quality of coverage and energy consumption. The problem can be modeled using a bipartite graph and an evolutionary algorithm could be employed to handle the activation and deactivation of the sensors. WSNs consist of spatially distributed sensors which cooperate among themselves to monitor any particular environmental or physical condition. The sensors are embedded into small wireless devices which are battery powered and have limited available resources like energy, processing speed and storage. Due to recent advancements in wireless technology, the utilization of Wireless Sensor Networks (WSNs) in various tracking and monitoring applications continues to grow at a high rate. As a result, many applications are significantly impacted by new developments in WSN research, particularly how the networks are self-organized. Such application domains include high-yield agriculture, glacier monitoring and animal tracking, in addition to various environmental and military applications.

The WSNs are expected to behave according to the application they are monitoring. For instance, a wireless sensor network monitoring an area of critical importance should monitor the entire region with a high degree of accuracy. So a model which can control the activation and deactivation of the sensor nodes according to what the situation demands is highly desirable. We aim to simulate a wireless sensor network with which we could determine which sensors to keep in an active state for any particular desired performance. Various physical factors such as the size of the area monitored, number of sensors monitoring the desired area etc. is considered, and the impact it has on the output produced is observed. In the rest of the chapter we discuss about the graph model that we employ to model the current situation and the algorithms that we use to get the desired results.

4.1 Proposed Model

The main objective of the research presented in this chapter is to analyze the desired situation and accordingly turn on the required number of sensors. The major factors that play a role in this are the network size and the density of sensors in the network. If the network is small and dense a lesser percentage of the total number of sensors can be turned on to monitor the entire area as compared to the percentage of sensors needed to achieve the same in a large and sparse network. Formally, the desired situation could be analyzed on the basis of the following factors:

1. Percentage of Coverage: Given a set of sensors $\{N_1, N_2, \ldots, N_n\}$ and a target area A which is divided into a set of sub-regions $\{S_1, S_2, \ldots, S_m\}$. The set of active sensors is considered, if there is at least one active sensor monitoring the sub-region, the sub-region is said to be covered. Accordingly a percentage of number of covered sub-regions to the total number of sub-regions is calculated to find the percentage of coverage.

2. Quality of Coverage: Given a sub-region S_m the number of sensors monitoring that sub-region should be found. The more sensors monitoring it, better the quality. Five levels for scaling the quality are assumed. The levels are dynamically calculated depending on the maximum and minimum values of quality available. For each sub-region it is found out in which level of quality the sub-region falls in. The total quality is found by finding the average of the quality of coverage of individual sub-regions.

3. Energy Saved: If a sensor is in active state it consumes energy else not. For finding the total energy saved in the network, the percentage of the total number of inactive sensors is found.

The entire wireless sensor network can be modeled by a bipartite graph G having two disjoint sets where one set of nodes m represents the sensor nodes and the other set of nodes n represent the sub-regions. An edge connects two nodes if that particular sensor monitors that particular sub-region as shown in Figure 4.1. In other words, any given WSN and the set of areas it needs to cover can be represented by a graph G as follows:

$G = (N \cup S, E)$; where,

N → Set of sensor nodes.

S → Set of sub-regions.

E → Edge which exists connects a node in N to a node in S if and only if that particular sensor monitors that sub-region.

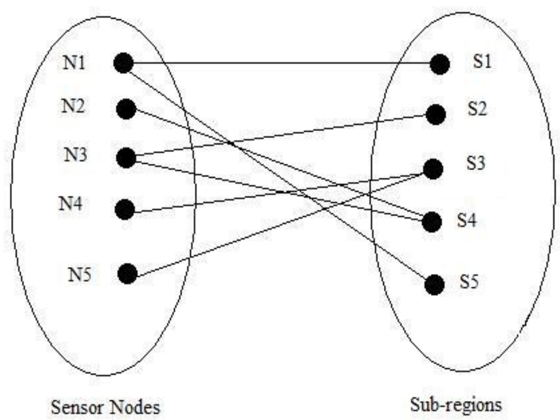


Figure 4.1: A Bipartite Representation of WSNs

In the figure we see that there exists an edge from N1 to S1 and S5 which implies that the sensor node N1 monitors the sub-regions S1 and S5. Similarly there exists an edge between sensor nodes N4, N5 to the sub-region S3; this implies that sensor nodes N4 and N5 monitor the sub-region S3. The three factors discussed above can be derived from the graph model as follows:

1. The percentage of covered area can be found by calculating the percentage of nodes in the sub-regions that have at least one edge connected to it.

2. The quality of coverage for individual nodes in the sub-region set is determined by finding the number of nodes in the sensor node set it is connected to. The total quality of coverage is the average quality for all the sub-regions.

3. The energy saved is the percentage of nodes in the sensor node set that has no edge.

As shown in the above example, a particular sensor could be affiliated with more than one sub-regions and one sub-region could be monitored by more than one sensor. Sensors could either be in the on state or else they are off. The sensors in the network can be represented by a string of 1's and 0's. If a particular sensor is on it is denoted by 1 else it is denoted by 0.

For any string, we can calculate its fitness function. To elaborate the fitness function we introduce the following sets and constants:

Let, $N = \{N_1, N_2, \ldots, N_n\}$ be the set of sensors

$S = \{S_1, S_2, \ldots, S_m\}$ be the set of sub-regions

For the implementation of this part, we have considered all the sensors to be of the same type and the role played by all the sensors are the same. The network at any particular time has to behave in a particular manner. The fitness function modifies the behavior of the network according to the user's requirement. The fitness function, f $\forall N, \forall S$ is defined as shown below.

$$f = \alpha P + \beta Q + \gamma R$$

where:

α, β, γ → tuning parameters.

P → Percentage of coverage.

Q → Quality of coverage.

R → Number of inactive nodes.

Depending on the values of the tuning parameters, the behavior of the network can be manipulated. The fitness function is used for determining the healthiest strings from a group of strings. Evolutionary algorithms are employed to get a set of strings, which keep on improving their fitness with every generation.

4.2 Proposed Evolutionary Approach

In a genetic algorithm, a population of strings (also called chromosomes) encodes individual solutions to an optimization problem. The evolution starts from randomly generated strings having length equal to the number of sensors and it evolves to better solutions. In our implementation, each individual sensor is represented by a 1-bit binary number called gene. The gene defines the status of the nodes as follows:

$$N_i = \begin{cases} 1 & \textit{if the sensor is active} \\ 0 & \textit{if the sensor is inactive} \end{cases}$$

A pseudo code of the standard genetic algorithm used to solve our problem is listed in Algorithm 1 below.

```
Randomly generate strings of first generation
Repeat
    ▪ Generate the number of elements and positions to mutate
    ▪ Have the elements at that position in the strings mutated
    ▪ Perform crossover with the mutated strings
    ▪ Calculate the fitness of the generated strings
    ▪ Select the desired number of healthiest strings
Until the healthiest strings have better fitness function values
```

Algorithm 4.1: Outlines of the Genetic Algorithm

- **Mutation** is the occasional random alteration of a gene of a chromosome. The purpose is of reintroducing useful genes that have been lost. This is shown in the figure 4.2.

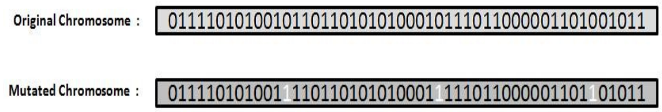


Figure 4.2: Mutation genetic operation.

- **Crossover** function select two individuals exchange their corresponding substrings creating offspring to deduce new individuals which are hopefully better. This is shown in figure 4.3.

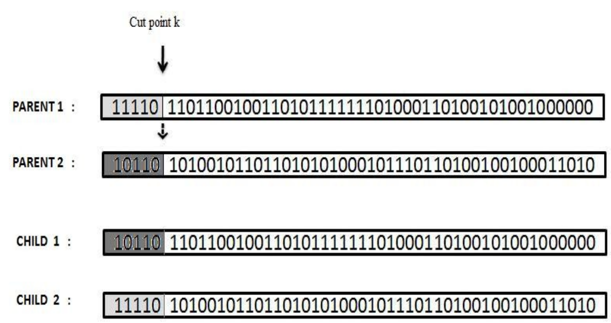


Figure 4.3: A crossover operation.

4.3 Accelerated Genetic Algorithm

The above algorithm helps in finding the best fit for any desired kind of solution. After certain generations, the algorithm comes up with a solution which cannot be further improved. The simple genetic algorithms use random searching in the search space around the parent strings due to which following issues arise:

- The best results could be overlooked if the search is not started from an appropriate point.
- The search space is so vast, it could take quite some time to process and present the best possible output.
- There is no assurance that the offspring is better than the parents.

Although the above stated problems cannot be totally eliminated, their impact can be reduced by partial elitism, intelligent mutation and healthy crossover respectively.

Partial Elitism

In pure elitism all the strings selected for further processing are the healthiest strings from the previous generation. Pure elitism may lead to premature convergence since they often explore a limited portion of the search space. To avoid this issue and explore more elements from the entire search space, we use partial elitism. In partial elitism some strings are obtained from the top-scoring elements of previous generation and the others are obtained randomly from the rest of the elements. Depending on the search space being explored, the degree of elitism can be altered. The main intention of introducing the randomly generated strings is to explore more areas in the search space that may not score high in earlier generations but may potentially lead to healthier elements in future generations.

Intelligent Mutation

Mutation is done to flip the state of some particular set of sensors which help in regaining certain properties of the network if lost. In case of normal mutation, this set of sensors – both the size and positions are randomly selected. This approach lacks certainty. The approach could at times take us to better solutions but because of its randomness the chances of it giving unproductive solutions is also fairly high. To overcome this shortcoming we propose the implementation of intelligent mutation where the target coverage is compared with the coverage of the current string. Depending on whether the target coverage is higher or lower the sensors are turned on or off respectively. The subregions that need to have the state of the sensors monitoring them changed are found; among these some subregions are randomly selected. All sensors monitoring the selected subregions have their state mutated. Using this approach, our search in the search space becomes more directed and progresses much faster to the desired goal.

Healthy Crossover

The healthy crossover is defined as follows:

$$X = \delta_1 X1 \oplus \delta_2 X2$$

where,

X → Offspring string.

X1, X2 → Parent strings.

δ_1, δ_2 → Health ratio parameters.

$\oplus$ represents crossover.

The health ratio parameters are calculated as follows:

$$\delta_1 = \frac{e^{f(X1)}}{e^{f(X1)} + e^{f(X2)}} \quad \ldots (1)$$

$$\delta_2 = \frac{e^{f(X2)}}{e^{f(X1)} + e^{f(X2)}} \quad \ldots (2)$$

where,

f (X1) → fitness of string 1.

f (X2) → fitness of string 2.

And from (1) and (2): $\delta_1 + \delta_2 = 1$

Depending on the values of health ratio parameters the offspring produced have δ_1 substrings belonging to the X1 parent string and δ_2 substrings belonging to the X2 parent string. Hence, if X1 is a better individual, the genes of X1 should have more proportion in X than that of X2.

4.4 Simulations

The model takes tuning parameters, number of sensors, size of substrings for crossover, number of strings for selection as input for simple GA and an additional number of strings for partial elitism for modified GA. The coding for the simulations has been done in Java.

A. Comparing GA versus Round-robin Algorithm

The impact of the number of sensors deployed is considered. The more the number of sensors deployed the better coverage and redundancy can be expected. In our simulations there are three types of networks – densely populated networks, moderately populated networks and sparsely populated networks. A network is dense if it has more than 50 sensors, networks having sensors between 25 and 50 are moderately populated networks and networks having 25 or less sensors are sparsely populated networks. All the three networks are implemented using the genetic algorithm we discussed and then with a round-robin scheduling algorithm. The robustness of the algorithm is tested by running the algorithm for extreme cases and gradually test the algorithm at various points moving from one extreme that focuses on the energy awareness aspect to the other extreme that focuses on percentage and quality of coverage. The input parameters are given such that the first input prioritizes coverage and quality of coverage, while the other input gradually shift the priority to the energy saved. Table 4.1 lists the outputs using genetic algorithms for densely populated networks. All the input tuning parameters are taken on a scale of 0 - 1. Zero being the least and one the maximum. The output parameters are on the scale of 0 – 100 and the number of crossover elements is 2. The total number of sensors in the densely populated is 60. Table 4.2 lists the outputs for simulations using the round-robin scheduling algorithms for densely populated networks.

Table 4.1: Simulation test results using evolutionary algorithms for densely populated networks.

	Input Parameters			**Output Parameters**		
	A	**β**	**γ**	**P**	**Q**	**R**
Case 1	0.9	0.8	0.1	97.53	72.22	31.66
Case 2	0.9	0.5	0.5	96.29	62.65	60.00
Case 3	0.7	0.3	0.6	91.36	70.61	70.00
Case 4	0.4	0.2	0.8	86.42	58.64	80.00
Case 5	0.1	0.1	0.9	59.25	35.80	86.67

Table 4.2: Simulation test results using round robin algorithm for densely populated networks.

	Number of Active Sensors	P	Q	R
Case 1	41	91.36	60.19	31.66
Case 2	24	88.89	49.69	60.0
Case 3	18	80.25	44.44	70.0
Case 4	12	65.43	29.63	80.0
Case 5	8	50.62	20.37	86.67

The number of sensors taken for a moderately populated network is 40. Table 4.3 and table 4.4 summarize the outputs for simulations for a moderately populated network using genetic algorithms and round-robin scheduling respectively. The number of crossover elements is taken as two.

Table 4.3: Simulation test results using evolutionary algorithms for moderately populated networks.

	Input Parameters			Output Parameters		
	A	β	γ	P	Q	R
Case 1	0.9	0.8	0.1	93.83	79.01	40.0
Case 2	0.9	0.5	0.5	90.12	67.90	52.5
Case 3	0.7	0.3	0.6	88.88	61.42	67.5
Case 4	0.4	0.2	0.8	72.84	58.95	80.0
Case 5	0.1	0.1	0.9	27.16	27.16	95.0

Table 4.4: Simulation test results using round robin algorithm for moderately populated networks.

	Number of Active Sensors	P	Q	R
Case 1	24	86.42	58.64	40.0
Case 2	19	82.72	48.46	52.5
Case 3	13	71.61	51.23	67.5
Case 4	8	48.14	33.33	80.0
Case 5	2	17.28	17.28	95.0

Finally, the total number of sensors taken in a sparsely populated network is 25. Table 4.5 and 4.6 lists the output for genetic algorithm and round robin respectively. The number of elements for crossover is two.

Table 4.5: Simulation test results using genetic algorithm for sparsely populated networks.

	Input Parameters			Output Parameters		
	A	**β**	**γ**	**P**	**Q**	**R**
Case 1	0.9	0.8	0.1	90.12	71.60	20.0
Case 2	0.8	0.5	0.5	81.48	55.55	56.0
Case 3	0.7	0.3	0.6	76.54	62.04	68.0
Case 4	0.4	0.2	0.8	59.26	48.46	80.0
Case 5	0.1	0.1	0.9	11.11	9.57	92.0

Table 4.6: Simulation test results using round robin algorithm for sparsely populated networks.

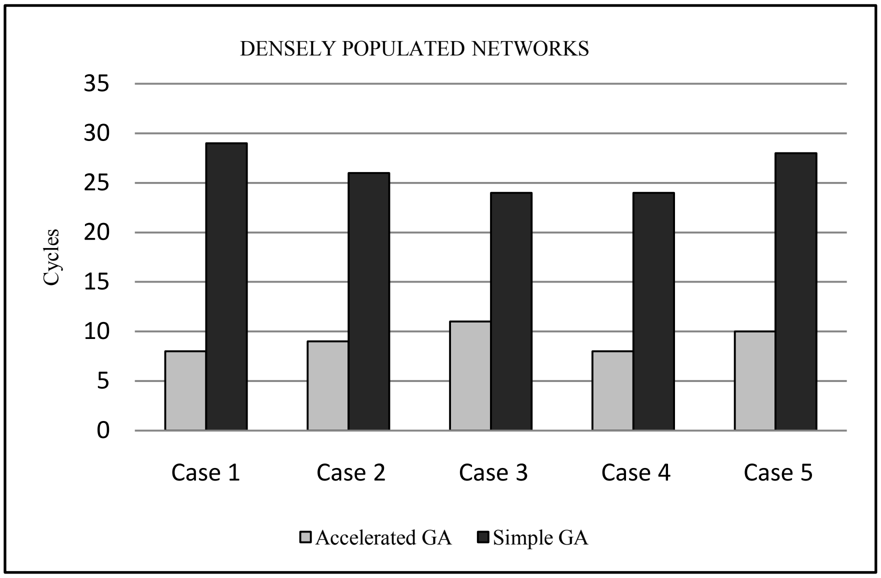
	Number of Active Sensors	P	Q	R
Case 1	20	81.48	40.12	20.0
Case 2	11	67.90	29.32	56.0
Case 3	8	54.32	32.72	68.0

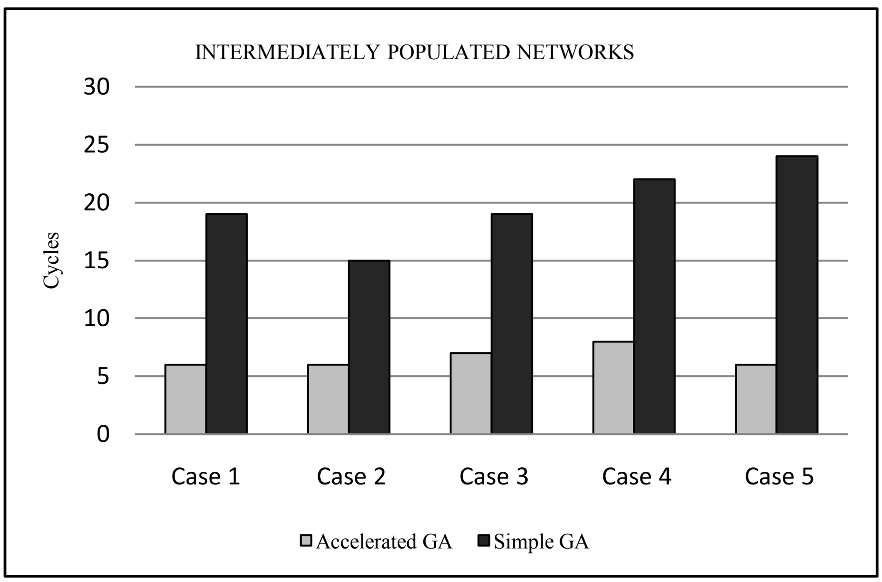
Case 4	5	46.91	38.89	80.0
Case 5	2	16.05	16.05	92.0

Comparing individual cases of all the three networks implemented with evolutionary algorithms to those implemented with round-robin scheduling algorithm, we find our algorithm gives better coverage and more efficient quality for the same amount of energy saved. Another observation that can be made from the readings is that as the networks go denser, both the percentage coverage and quality is significantly higher or if approximately the same amount of coverage and quality is achieved then more energy is saved. Consider the case 2 for both the densely populated and moderately populated networks using the genetic algorithm, although the same inputs are given for both the densely populated networks tend to produce systems having higher coverage and quality with more energy saved.

B. Comparing GA versus Accelerated GA

The algorithms are compared on all the three types of networks. The output parameters for both the algorithms are more or less the same but the number of iterations needed to reach there is reduced in accelerated GA. Both the algorithms have a counter which keeps a track of the number of cycles needed to reach the stable state. A network is said to have reached a stable state if stays for a certain number of cycles with no improvement in the best fitness function. The results of this experiment are as shown in Figure 4.4. The impact of this algorithm increases with the increase in the number of sensors deployed. In most of the applications, the number of sensors deployed is very high; in cases like these accelerated GA play a great role in reducing computations and in turn reduces the energy spent.


DENSELY POPULATED NETWORKS
Cycles
35
30
25
20
15
10
5
0
Case 1
Case 2
Case 3
Case 4
Case 5
Accelerated GA
Simple GA


INTERMEDIATELY POPULATED NETWORKS
Cycles
30
25
20
15
10
5
0
Case 1
Case 2
Case 3
Case 4
Case 5
Accelerated GA
Simple GA

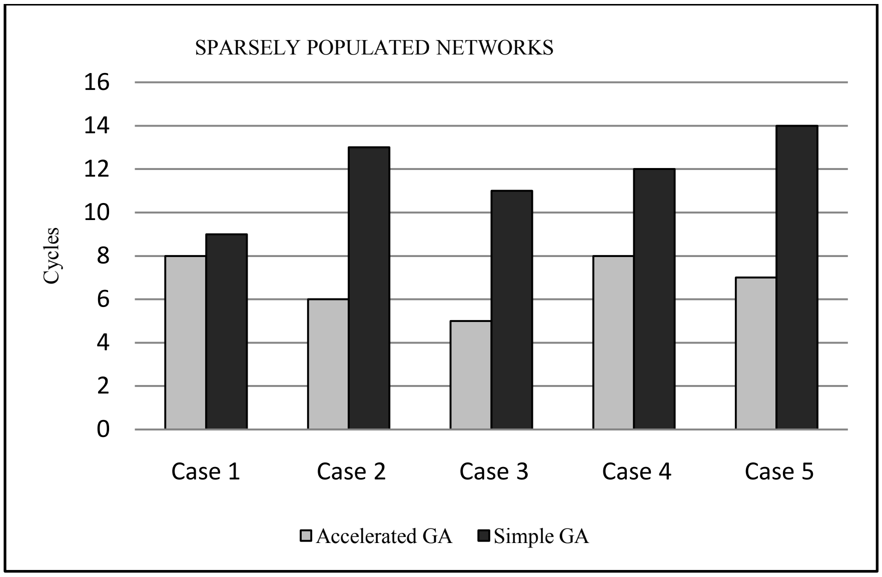


Figure 4.4: Graphs representing the number of cycles needed to reach the desired state.

Chapter V - Combinatorial Approach

Proficient cluster formation in wireless sensor networks reduces the total energy consumed by the network and prolongs the life of the network. There are various clustering approaches proposed, depending on the application and the objective to be attained. There are situations in which sensors are randomly dispersed over the area to be monitored. In this chapter, we attempt to propose a solution for such senarios using heterogeneous networks where a network has to self-organize itself depending on the physical locations of sensors, cluster heads etc. We also attempt to provide a flexible solution which can be applied to any network irrespective of density of resources deployed in the network. Wireless sensor networks (WSNs) consist of a large number of sensors; sensors are small wireless devices having limited resources like energy, processing speed and storage. With the recent technology advances it is possible to produce small and low cost sensors making it economically feasible to deploy sensors in large numbers. Sensors usually do the role of measuring some ambient conditions and reporting it to the processing node. While measuring the ambient conditions, the wireless sensor networks face a number of challenges for the smooth operation of the networks inviting researchers to explore different alternate paths for attaining the desired results. The previous chapter had focused on obtaining an algorithm with the help of which several optimization criteria like percentage of coverage, quality of coverage and energy consumption. The algorithm aims to attain a solution which represented the on/ off status of the sensors involved in monitoring. In this chapter, we further extend our research by devising a way by which the active sensors could economically report the sensed data to the processing nodes. Instead of each individual sensor directly reporting to the processing node, the sensors in the WSNs are clustered. Clustering provides network scalability and network topology stability and has energy saving attributes.

A clustering scheme is a criterion depending on which the clusters are formed. There are many different clustering schemes which prioritize different properties depending on the different needs of the application. Clustering schemes are categorized depending on what objective the cluster intends to attain [24]: Dominating-Set based clustering, low-maintenance clustering, mobility-aware clustering, energy-efficient clustering, load balancing clustering, combined based metrics clustering. The clustering scheme has also been classified according to the cost incurred in some aspects [24] for instance the explicit control message for clustering, ripple effect of re-clustering, stationary assumption for cluster formation, constant computation round and communication (message) complexity. An alternate way to classify clustering specifically in ad-hoc networks are the following [25]: single-hop or multi-hop, location based or non-location based, synchronous or asynchronous (depending on the network topology) and stationary nodes or mobile nodes. Clustering in networks also depends on the type of network that is being considered. Clustering is performed on sensor networks which are either homogeneous– all the sensor nodes are identical in built and functionality or heterogeneous– the network consists of sensors which differ from each other in built or functionality. Both categories of networks have to deal with the overhead of cluster construction process. The homogeneous networks also have an additional overhead of cluster head selection.

5.1 Proposed Model

In a heterogeneous sensor network self-organization continues to be a prominent feature due to increase in the complexity in managing the network as most of the routing paths are dynamically decided. In our model, all the nodes deployed for monitoring the region of interest is classified into one of the following sets: set of sensor nodes, set of cluster heads and set of sink nodes. The clustering model we propose focuses on handling the problem of determining which nodes of one set report data to which node of the other set. Considering the facts that the data handling capacity of every node in the system is limited and the transmission distance of the nodes is restricted, the major challenge that the system faces is not only to find the cheapest option for an individual node but also to confirm that the cheapest option for that node does not compel the overall system’s communication cost to rise and finally assuring that no other allocation has a cheaper system communication cost. We suggest that the operation of node clustering can be modeled by graph clustering, which groups vertices of a graph into clusters based on certain conditions. Graph clustering can be broadly divided into two categories: global clustering and local clustering [20]. The difference between the two types of clustering being that in global clustering every vertex on a graph is allocated to a cluster and in local clustering only a certain subset of vertices is allocated to a cluster. Applications like WSNs usually use global clustering.

Graph Model

Multi-stage graph is usually used in cases where there is a connected graph optimization problem having several stages. Each stage contains a set of nodes. The edges of the graph are used to connect nodes in different stages. There are no edges between nodes of the same stage or non-adjacent stage. The entire WSN can be modeled by a multi-stage graph having three stages as shown in figure 5.1. Where the first stage of nodes represents the set of sensors, the second stage represents the set of cluster heads and the third stage represents the set of sink nodes. An edge connects two nodes if that particular sensor (or cluster head) can communicate with the particular cluster head (or sink node). The weight on the edge represents the distance between the two nodes. The network can be represented by the multi-stage graph as follows:

$G = (N \cup C \cup S, E1 \cup E2)$; where,

N → Set of sensor nodes.

C → Set of cluster heads.

S → Set of sink nodes.

E1 → Set of edges connecting N and C.

E2 → Set of edges connecting C and S.

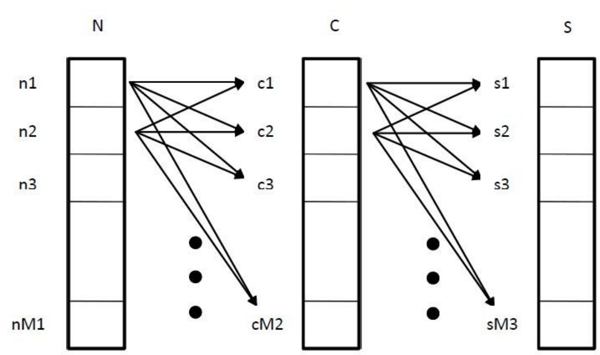


Figure 5.1: Multi-stage graph representation of Heterogeneous Senor Network

In the figure, we see that there are M1 sensor nodes, M2 cluster head nodes and M3 sink nodes. There exists an edge that connects n1 to c1, c2, c3 and cM2 all the edges have the respective weights associated with them representing the distance between the two nodes. The total system is considered and considering the maximum number of sensors that can be allocated to a cluster head appropriate edges are shortlisted and accordingly each sensor is allocated to some particular cluster head. A network could have more than one sink node depending on the size of the network; considering the set of cluster heads and sink nodes depending on the distance between individual cluster heads and sink nodes a particular cluster-head is clustered with one a particular sink node. Also the cost of communication between any two individual elements is directly proportional to the distance between the two elements, for simplicity sake we assume the cost of communication for every one unit of distance is one unit of cost.

5.2 Proposed Combinatorial Algorithm

The proposed algorithm aims to attain cheapest possible allocation of resources in one set to the resources in the successive set. In graph theory, maximum matching algorithms gives us an independent edge set with no common vertices such that the combined weight of the edges selected is the maximum possible for that graph. Our issue can be translated to a maximum matching problem as we need all resources allocated but with the modification that we need the minimum possible weight. Hence, our problem can be termed as a “minimum matching algorithm” that is a set of independent edges where the combined weight is as minimum as possible. The initial graph is obtained as described above, in order to make our graph eligible to have the minimum matching algorithm to be applied to it the graph needs to be remodeled using the graph expansion algorithm as described in algorithm 5.1.

1. Consider the two set of nodes – set S1 and set S2.
2. Generate a 2-D array with the following parameters:
   a. Rows representing the elements of set S1.
   b. Columns representing the elements of set S2.
   c. Individual value in the array representing the distance between an *ith* element in set S1 and a *jth* element in set S2. with i and j representing the row and column number respectively.
3. If the number of rows is greater than the number of columns.
   a. Replicate the number of columns until the total count of elements of set S1 is not less than the product of the number of elements of set S2 and the resource handling capacity of an individual element of set S2.
   b. Replace the original array with the modified array.

Algorithm 5.1: Graph expansion Algorithm

The algorithm 5.1 primarily focuses on the other parameter that we consider in our experiment, which is the data handling capacity of any resource. For any resource the data handling capacity is limited due to which there is a limit of number of resources that can report to it. The resource handling capacity of individual elements of both the sets – set of cluster heads and set of sink nodes is taken as input from the user. The algorithm is applied individually to both the stages of the multi-stage graph and can be better explained with an example. Consider any stage of the multi-stage graph for instance the first stage where the sensors report to cluster heads. Assuming a cluster head can handle data from t sensors. Replicate the set of cluster heads a number of times such that the number of cluster heads is not less than t times the number of cluster heads. In the figure 5.2 we see there are three sensors and two cluster heads, assuming the maximum number of sensors a cluster head can handle is two, the number of cluster heads is replicated once making the count of number of cluster heads four which is not less than four - t times the number of cluster heads (as both t and the number of cluster heads are two in this case). On the transformed array, the minimum matching algorithm is implemented giving us an optimal allocation of sensors to cluster heads. The minimal matching algorithm uses a combinatorial approach which considers the transformed array as a whole and aims at finding the cheapest allocation for the system which in terms of the array would mean finding a specific value *j* for every value *i* where *i* and *j* represent the row number and column number respectively.

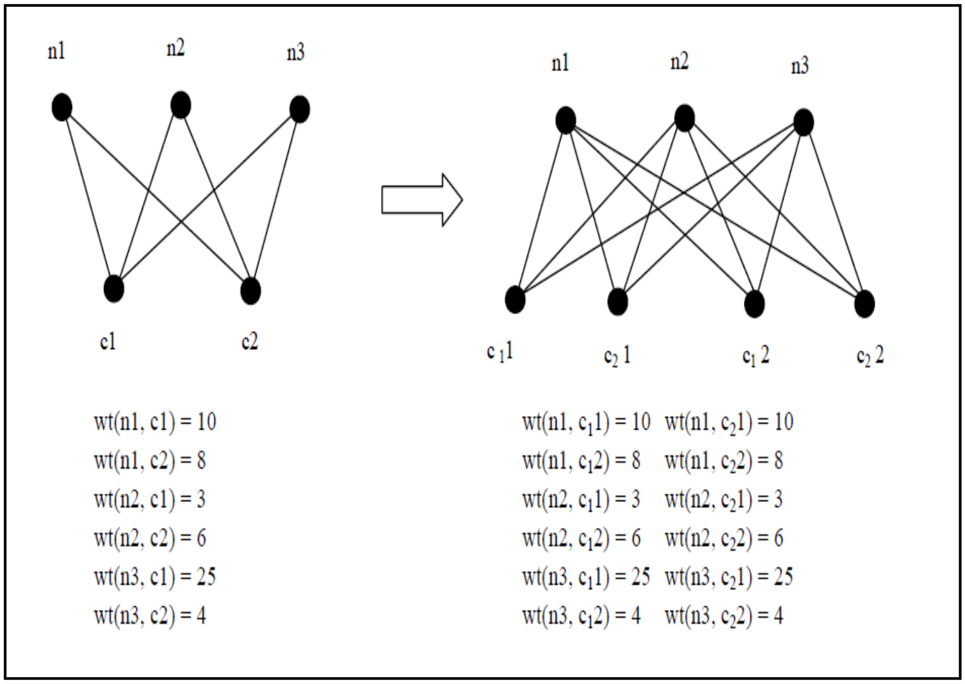


Figure 5.2: Expanded graph with replicated nodes.

The communication cost for any specific element of set S1 to a specific element of set S2 is the value of the element in the array having the row number as the index of the element of set S1 and column number as the index of the element of set S2. The sum of communication expense incurred by all the individual elements of set S1 is the total expense the system has to pay for communication. In terms of the array, for every row only one unique column number has to be selected and the sum of the elements represented by the indices of the specific row number and the column number selected for it should be as low as possible. We have used the Hungarian algorithm to achieve this; the Hungarian algorithm implements the desired optimization. It is described in the algorithm 5.2. As an example, the algorithm is applied on an array termed as array A.

1. Let array A be the array on which the algorithm is to be applied.
2. For every row in A, find the smallest variable and subtract the smallest variable from every other variable of the row. Let the modified array be array A'.
3. For every column in A', find the smallest variable and subtract the smallest variable from every other variable of the column. Let the modified array be array A''.
4. The array A'' is now expected to have a few variables having a value of zero.
5. Have the appropriate zeros selected from A''. A zero is said to be appropriate if it is the only zero present in its row or column.
6. If a particular zero is selected because it is the only zero in its row (or column) the presence of all other zeroes in its column (or row) is voided and the column (or row) is said to be covered.
7. Array A'' will be in one of the following conditions:
   a. All the rows have been assigned and the matrix is fully covered.
      i. Stop.
      ii. The position of zeros in the array A'' represent which *ith* resource reports to which *jth* resource. Where i and j represent the row and column number respectively.
      iii. The total communication cost is calculated by finding the sum of the elements of A located at the same position where the zeros are located in A''.
   b. All the rows have not been assigned and the matrix is not fully covered.
      i. Randomly mark any uncovered zero as covered.
      ii. Have a flag set indicating that an uncovered zero has been forcibly marked covered.
      iii. Go to step 5.
   c. All the rows have been assigned and the matrix is not fully covered.
      i. If any uncovered zero is never forcibly marked as covered
         1. Create new zeros by subtracting the value of the smallest uncovered cost from all the uncovered costs.
         2. Add the smallest uncovered value to all the double-covered values.
         3. Go back to step 5.
      ii. Else
         1. Mark all uncovered rows.
         2. Mark all unmarked columns that have zero in the marked rows.
         3. Mark all unmarked rows that have assignments in the marked columns.
         4. Repeat 2 & 3 until no changes are observed.

5. Create new zeros by subtracting the value of the smallest uncovered cost from all the uncovered costs.
6. Add the smallest uncovered value to all the double-covered costs.
7. Go back to step 5.

8. The position of zeros in the array A'' represent which *ith* resource reports to which *jth* resource. Where i and j represent the row and column number respectively.
9. The total communication cost is calculated by finding the sum of the elements of A located at the same position where the zeros are located in A''.

Algorithm 5.2: Proposed Combinatorial Optimization Algorithm

We try to further explain the above stated two algorithms with the help of an example. The algorithms are applied on the example shown in figure 5.2, the transformation of the matrix due to individual algorithms is as shown in figure 5.3. In the figure S1 is the set of sensors and S2 is the set of cluster heads. From the step 8 of the figure it can be observed that the cost of communication (sum of selected elements of the matrix) is 15. Hence, the algorithms help in finding the most economical assignment of sensors to the cluster head and the most economical assignment of cluster heads to sink nodes.

Algorithm 1

1. 2-D array is formed with S1 and S2 and the values representing the distance.

	c1	c2
s1	10	8
s2	3	6
s3	25	4

2. Array is modified as the number of rows is greater than the number of columns.

	c1	c2	c1	c2
s1	10	8	10	8
s2	3	6	3	6
s3	25	4	25	4

Algorithm 2

3. A is the modified array generated by algorithm 1. A' is generated by subtracting the smallest variable from each row.

	c1	c2	c1	c2
s1	2	0	2	0
s2	0	3	0	3
s3	21	0	21	0

4. A'' is generated by subtracting the smallest variable from each column.

	c1	c2	c1	c2
s1	2	0	2	0
s2	0	3	0	3
s3	21	0	21	0

5. The lone zero in c1 is selected due to which s2 is voided.

	c1	c2	c1	c2
s1	2	0	2	0
s2	0	3	0	3
s3	21	0	21	0

6. All the rows are not assigned and matrix is not fully covered, uncovered zero is forcibly covered voiding c2.

	c1	c2	c1	c2
s1	2	0	2	0
s2	0	3	0	3
s3	21	0	21	0

7. The lone zero in s3 is selected, voiding c2.

	c1	c2	c1	c2
s1	2	0	2	0
s2	0	3	0	3
s3	21	0	21	0

8. Actual elements selected in Array A.

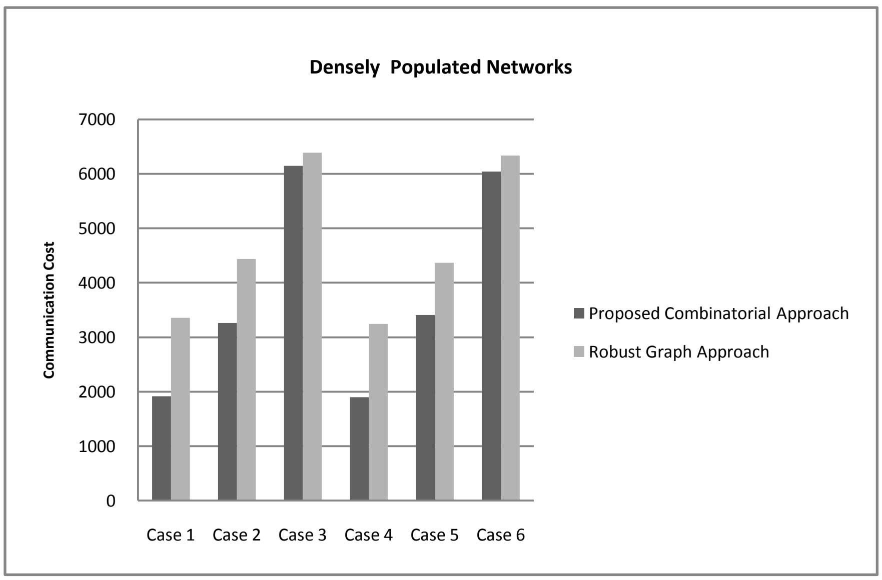
	c1	c2	c1	c2
s1	10	8	10	8
s2	3	6	3	6
s3	25	4	25	4

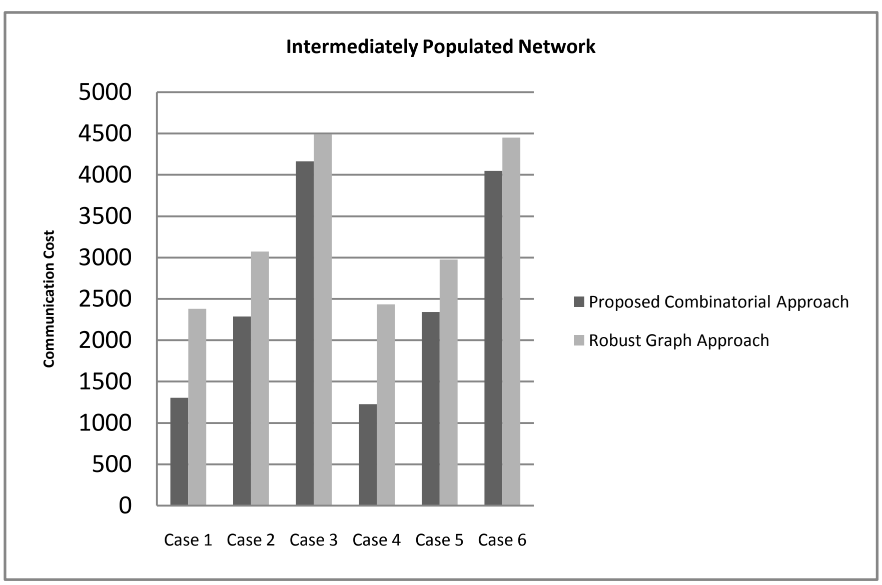
Figure 5.3: Illustration of the algorithms on the example.

5.3 Simulations

To illustrate the performance of the proposed algorithm, we have compared the outputs produced by the proposed combinatorial algorithm with the outputs produced using traditional robust graph approach. In practical applications, many times few of the components (like sensors) could be situated far off from other components (like cluster heads) to which it reports to, to make our experiments more practical we have intentionally introduced weak links in our simulations. The robust graph approach is a strong approach for dealing with the clustering problem; this approach also consists of a multi-stage graph with a set of nodes for each - the sensors, cluster heads and the sink nodes. At any stage when two sets of nodes are considered, the minimum available weight is selected until all the nodes of one set are allocated. Both the models take the following inputs: number of sensors deployed, number of cluster heads deployed and the number of sink nodes available. The quality and hardware superiority of any networking device deployed determines how much and from how many devices can it handle the data from. For example the better the superiority of a cluster head the more number of sensors can report to it. Both the algorithms implemented permit the discussed flexibility by taking the maximum number of sensors a cluster head can handle and the maximum number of cluster heads a sink node can handle. The impact of the number of sensors deployed is also considered. Better redundancy and coverage can be expected with the increase in the number of sensors being deployed. In our simulations there are three types of networks – densely populated networks, moderately populated networks and sparsely populated networks. A network is dense if it has more than 50 sensors, networks having sensors between 25 and 50 are moderately populated networks and networks having 25 or less sensors are sparsely populated networks.

As stated earlier, the cost of communication between any two devices is directly proportional to the distance between them. The simulations are carried out assuming the cost of communication is one unit for every one meter. Sensors, Cluster heads and sink nodes are randomly distributed on the area to be monitored. The proposed algorithm is carried out on all the three types of networks. The figure 5.4 compares the communication cost between sensor and cluster head for both the approaches for all the three networks under similar conditions and figure 5.5 does the same for the communication cost between cluster heads and sink nodes. To test the behavior of the networks under different conditions, the count of the number of cluster heads and number of sink nodes is changed in different cases. Case 1 has 20 cluster heads and 5 sink nodes are deployed. Case 2 -10 cluster heads and 5 sink nodes; case 3 – 5 cluster heads and 5 sink nodes; case 4 – 20 cluster heads and 2 sink nodes; case 5 – 10 cluster heads and 2 sink nodes and case 6 – 5 cluster heads and 2 sink nodes are deployed.





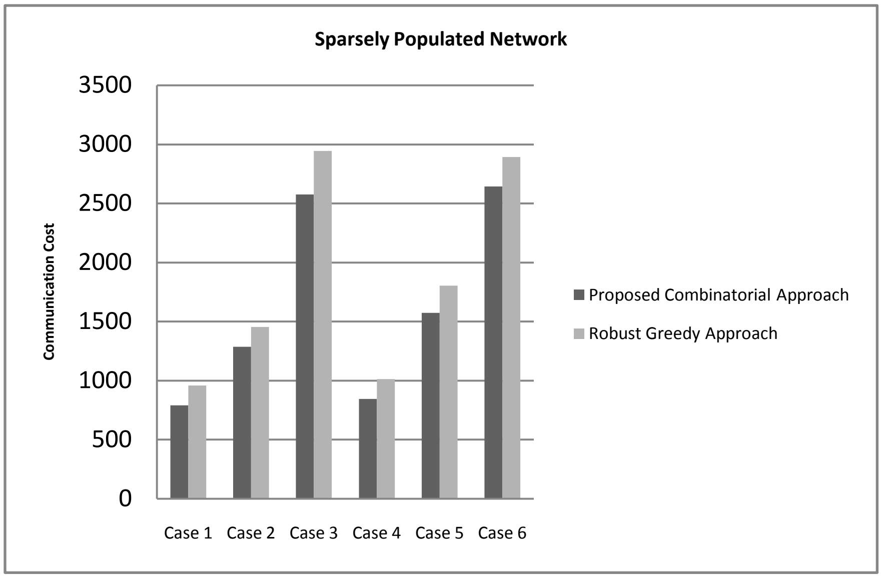
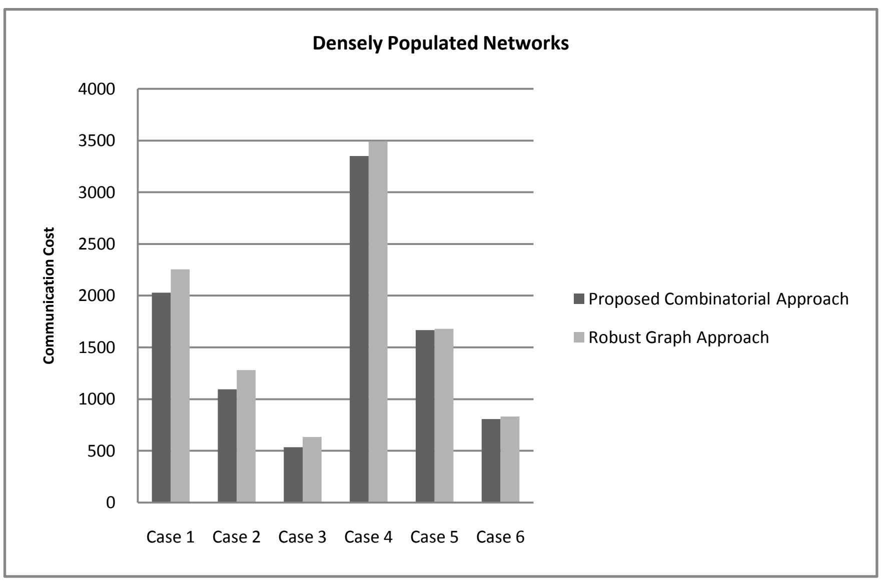
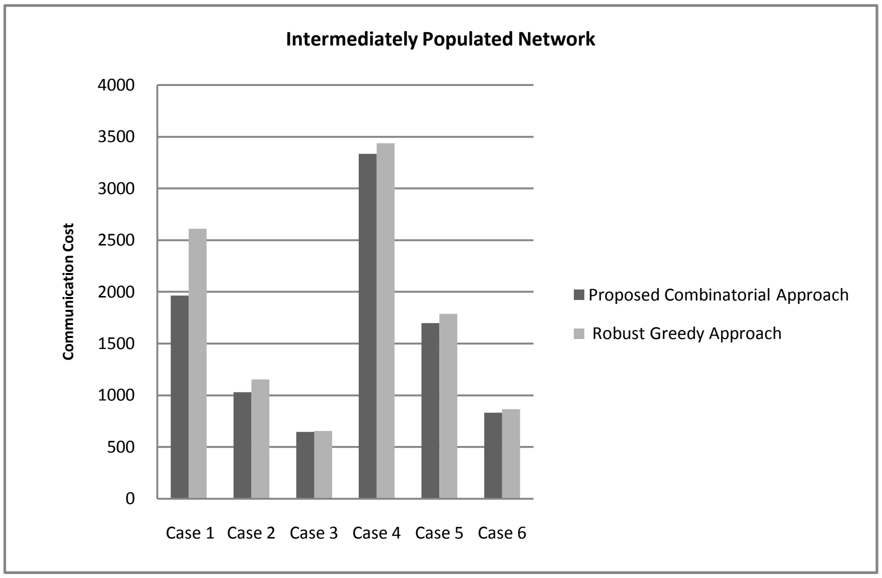


Figure 5.4: Graphs representing the communication cost for sensor - cluster head communication.





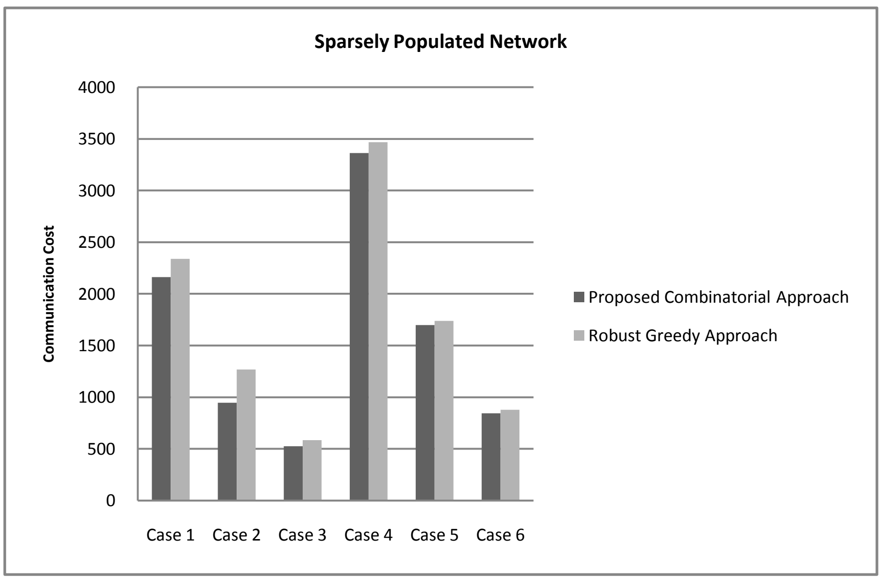


Figure 5.5: Graphs representing the communication cost for cluster head - sink communication.

The experiments that we have conducted aim for devising an algorithm that optimizes the total energy spent by the network. Since the number of elements that could report to any element in the next stage is limited it could force any individual element to take an option which may not be the cheapest but beneficial for the whole system. From the graphs we can observe that in most of the cases the proposed algorithm gives better solutions as compared to the robust graph approach. The figure 5.4 shows that the proposed algorithm is much better than the robust algorithm and the prominence of the proposed algorithm is not as significant in figure 5.5 which leads us to confirm that the algorithm works better when the ratio of devices reporting data to the devices receiving data is higher. Another major advantage of the proposed algorithm over the robust approach is that it does not follow a greedy approach by making choices based on a global overview. The robust approach makes choices that look the best at that moment. In many cases, the attained optimal solution by the robust approach maybe at par with our proposed solution but it could fail at critical conditions and hence is not so reliable.

Chapter VI - Effect of sequence of execution

6.1 Introduction

Different networks have different priorities and challenges depending on the area they are monitoring. For example a sensor network deployed to monitor some physical condition in a farm is stationary and the density of the sensors can be varied according to the size of the farm where as a sensor randomly dispersed to monitor living things trapped in glacier or avalanche could have a few sensors monitoring a large area here the sensors have to face a more challenging role.

Various researchers have proposed unique solutions to different kinds of problems. Seeing the nature of the algorithms that we have implemented, we can predict their behavior. Ideally the area to be monitored in a few applications where wireless sensor networks are deployed is predictable and in some cases the area is not so predictable. So in some cases it is desired that the algorithms have a huge search space to explore before coming to a result whereas it may not be needed in some cases and would tend in excessive energy usage which is not good for the system. Different results can be obtained depending on the sequence of execution. We need to explore and come to a conclusion which particular sequence is beneficial in which conditions.

6.2 Sequence of Execution

In any WSN network the energy saved by the network plays a crucial role. All networks aim at saving energy at every possible stage. As discussed earlier, researchers have attempted to minimize the energy expenditure at every possible level. As far as the issue of determining which sensors should be turned on for monitoring and to which cluster head should the active sensor report its data to could be handled in one of the following ways:

1. Genetic-Combinatorial Approach: Depending on the required fitness function, the required sets of sensors are turned on and the combinatorial algorithm is applied on the set of active sensors which will cluster the active sensors to the appropriate cluster heads. The sequence executed is as follows:

    a. Initially genetic algorithm is applied to the network.

b. Genetic algorithm considers the required fitness from the network and accordingly proposes a solution.

c. The locations of sensors that are in active state in the solution are considered.

d. Combinatorial algorithm is applied to the active sensors to cluster it to the appropriate cluster heads.

2. Combinatorial-Genetic Approach: The combinatorial algorithm is applied initially to all the sensors and clusters are formed. Genetic algorithms are applied to determine which sensors are to be turned off for the desired fitness level, while determining this the distance between the network devices is considered. The sequence executed is as follows:

a. Initially combinatorial algorithm is applied to the network.

b. All the sensors are clustered to the appropriate cluster heads.

c. The sensors are sorted in an ascending order depending on the distance between the sensors and cluster heads.

d. The desired energy level in the required fitness is considered accordingly sensors having longer reporting are turned off.

e. Genetic algorithm is applied to the network to attain the desired fitness.

The two different approaches help us determine the impact of the sequence of execution of the different steps. The advantages and disadvantages of the different execution sequence can be studied and depending on the same for any particular situation which approach is more beneficial can be determined. Figure 6.1 and 6.2 show us both the sequences more elaborately.

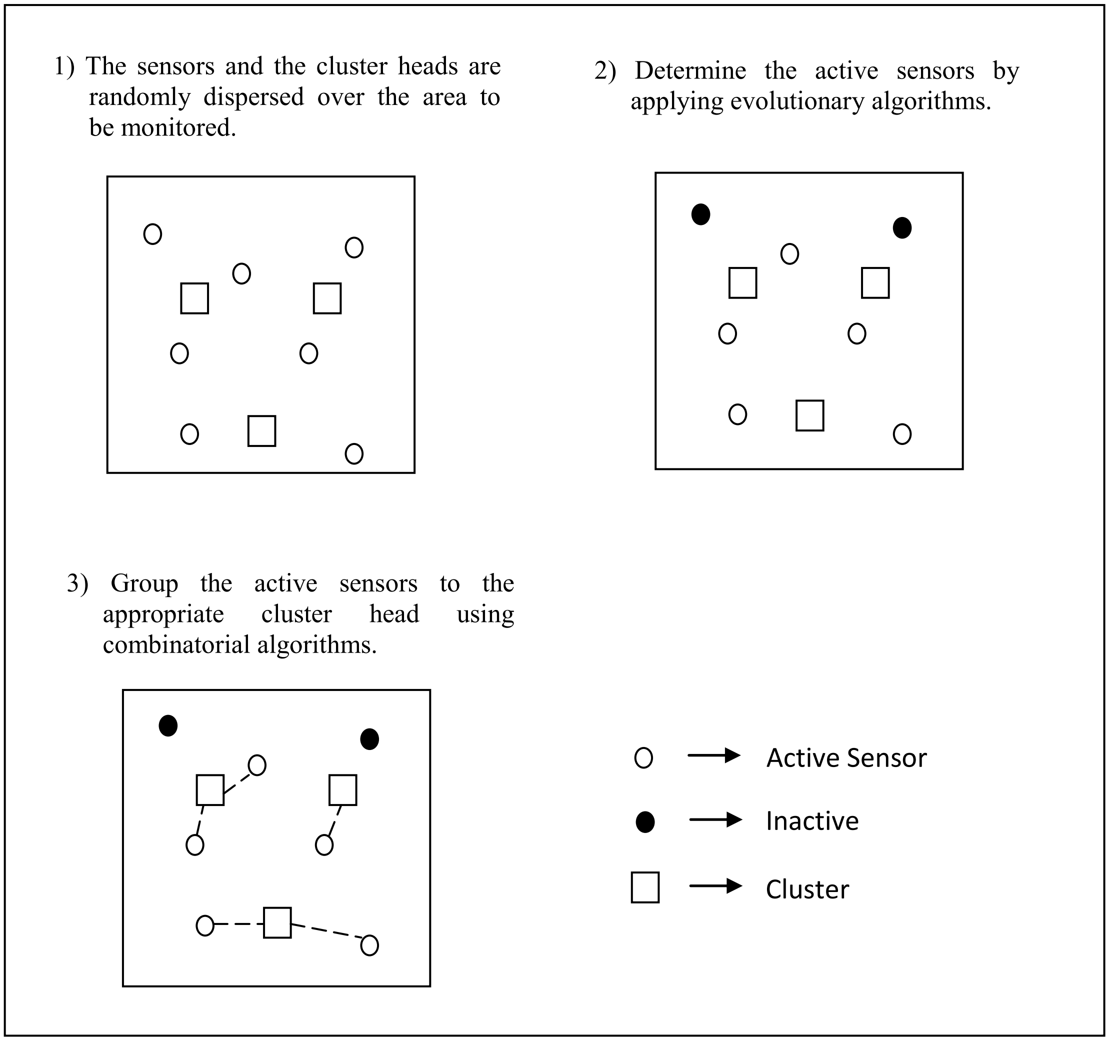


Figure 6.1: Sequence 1 - Evolutionary Algorithm - Combinatorial Algorithm

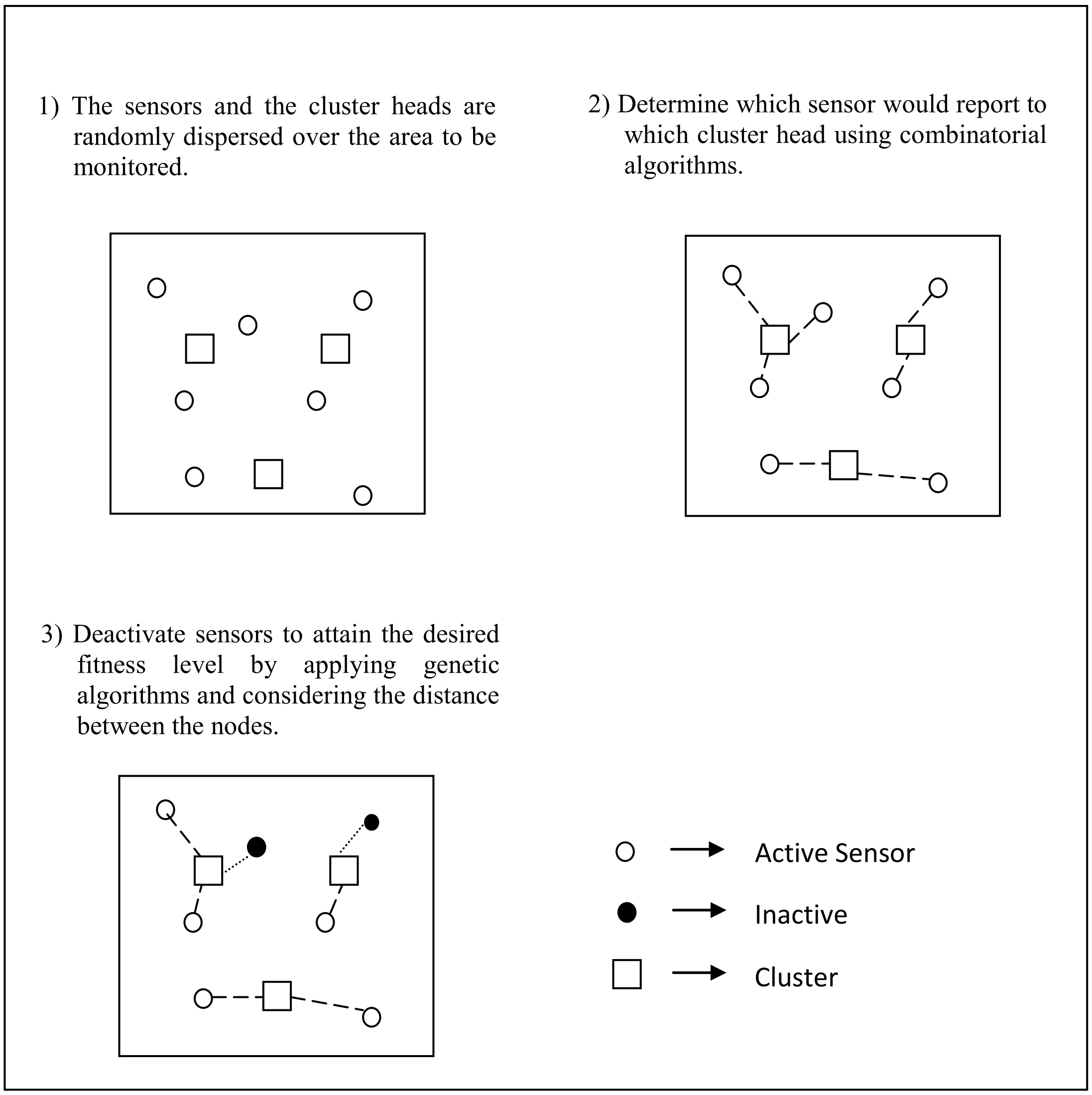


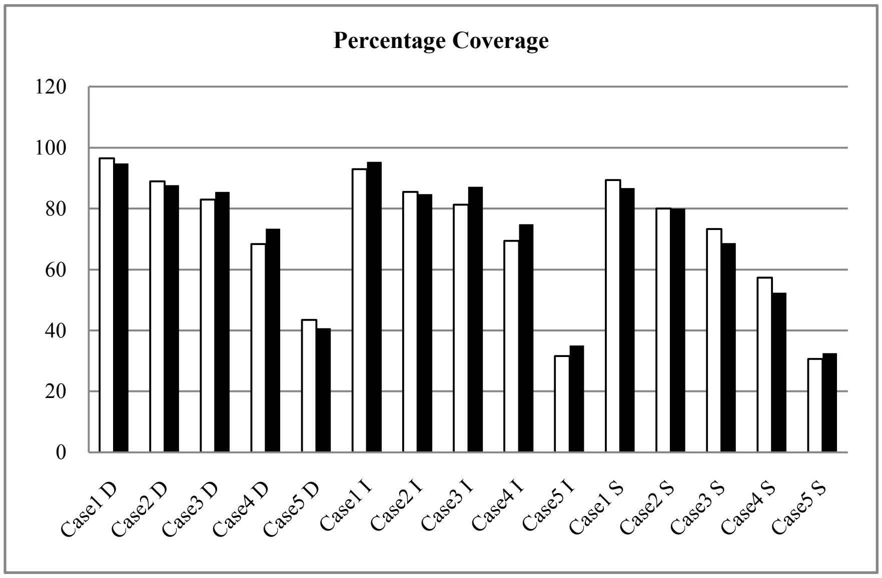
Figure 6.2: Sequence 2 - Combinatorial Algorithm - Evolutionary Algorithm

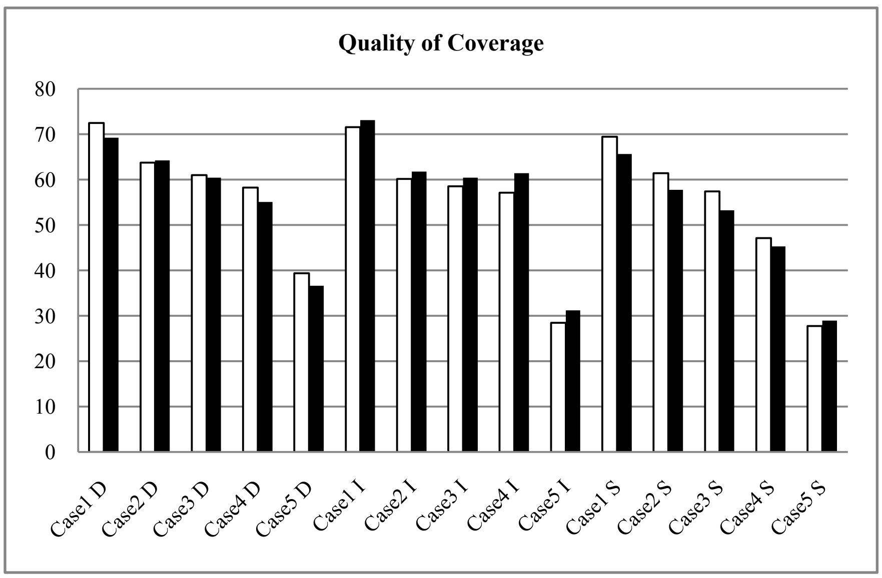
6.3 Simulations

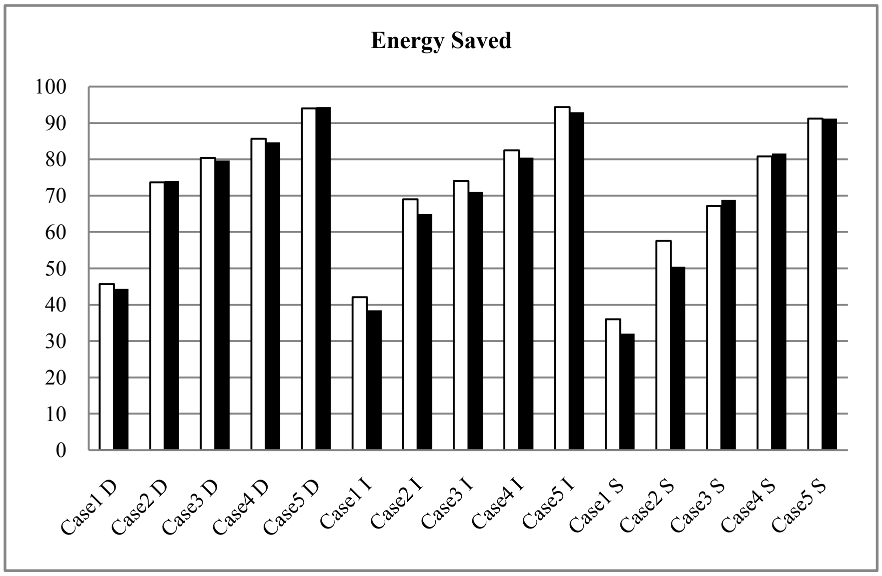
The difference that the sequence of the algorithms has is compared using following parameters:

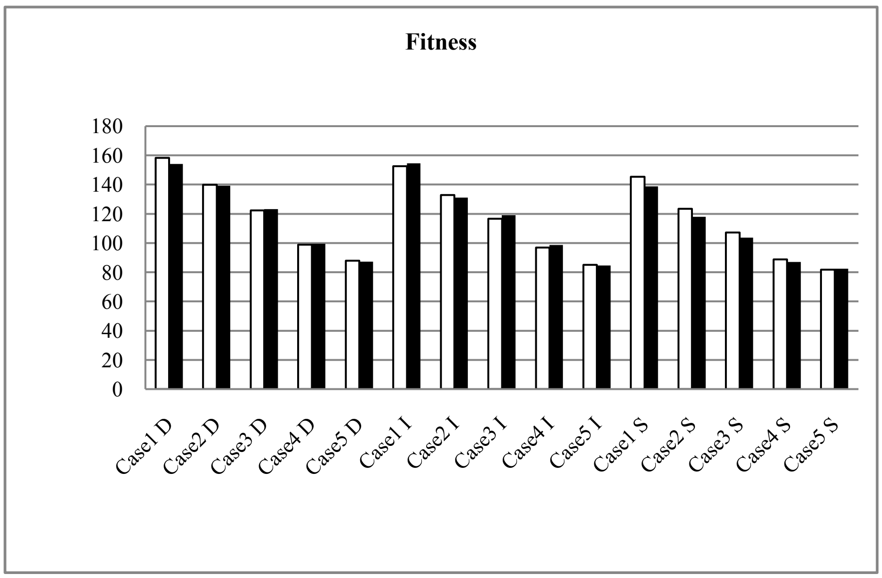
- Percentage of coverage: The total percentage of subregions covered.
- Quality of coverage: The average quality of coverage received by each subregion.
- Energy saved: The total percentage of inactive sensors.
- Fitness: Fitness is calculated as described in the previous sections using percentage of coverage, quality of coverage and energy saved.
- Number of Cycles: The genetic algorithms use iterations to come to the best possible solution. The numbers of cycles are the number of iterations incurred.
- Communication cost: Sensors report to cluster heads and they are grouped into clusters. Communication cost is the total cost spent in communication.

The impact of the number of sensors deployed is also considered. It is expected that the more the number of sensors are deployed the better coverage and redundancy can be attained. Our simulations consider three types of networks – densely populated networks, moderately populated networks and sparsely populated networks. A network is dense if it has more than 50 sensors, networks having sensors between 25 and 50 are moderately populated networks and networks having 25 or less sensors are sparsely populated networks. The robustness of the algorithm is tested by running the algorithm for extreme cases and gradually test the algorithm at various points moving from one extreme that focuses on the energy awareness aspect to the other extreme that focuses on percentage and quality of coverage. In the graphs dense, intermediate and sparse are represented by D, I and S respectively. We have tested for five cases of each type of network; the results are as shown in figure 6.3. In the first case the genetic algorithms are executed and the results obtained from these are given as input to the combinatorial algorithms and in the second case, the combinatorial algorithms are executed first and their results are fed as inputs to the genetic algorithms.


Percentage Coverage
120
100
80
60
40
20
0
Case1 D
Case2 D
Case3 D
Case4 D
Case5 D
Case1 I
Case2 I
Case3 I
Case4 I
Case5 I
Case1 S
Case2 S
Case3 S
Case4 S
Case5 S


Quality of Coverage
80
70
60
50
40
30
20
10
0
Case1 D
Case2 D
Case3 D
Case4 D
Case5 D
Case1 I
Case2 I
Case3 I
Case4 I
Case5 I
Case1 S
Case2 S
Case3 S
Case4 S
Case5 S


Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Case1 D
Case2 D
Case3 D
Case4 D
Case5 D
Case1 I
Case2 I
Case3 I
Case4 I
Case5 I
Case1 S
Case2 S
Case3 S
Case4 S
Case5 S


Fitness
180
160
140
120
100
80
60
40
20
0
Case1 D
Case2 D
Case3 D
Case4 D
Case5 D
Case1 I
Case2 I
Case3 I
Case4 I
Case5 I
Case1 S
Case2 S
Case3 S
Case4 S
Case5 S

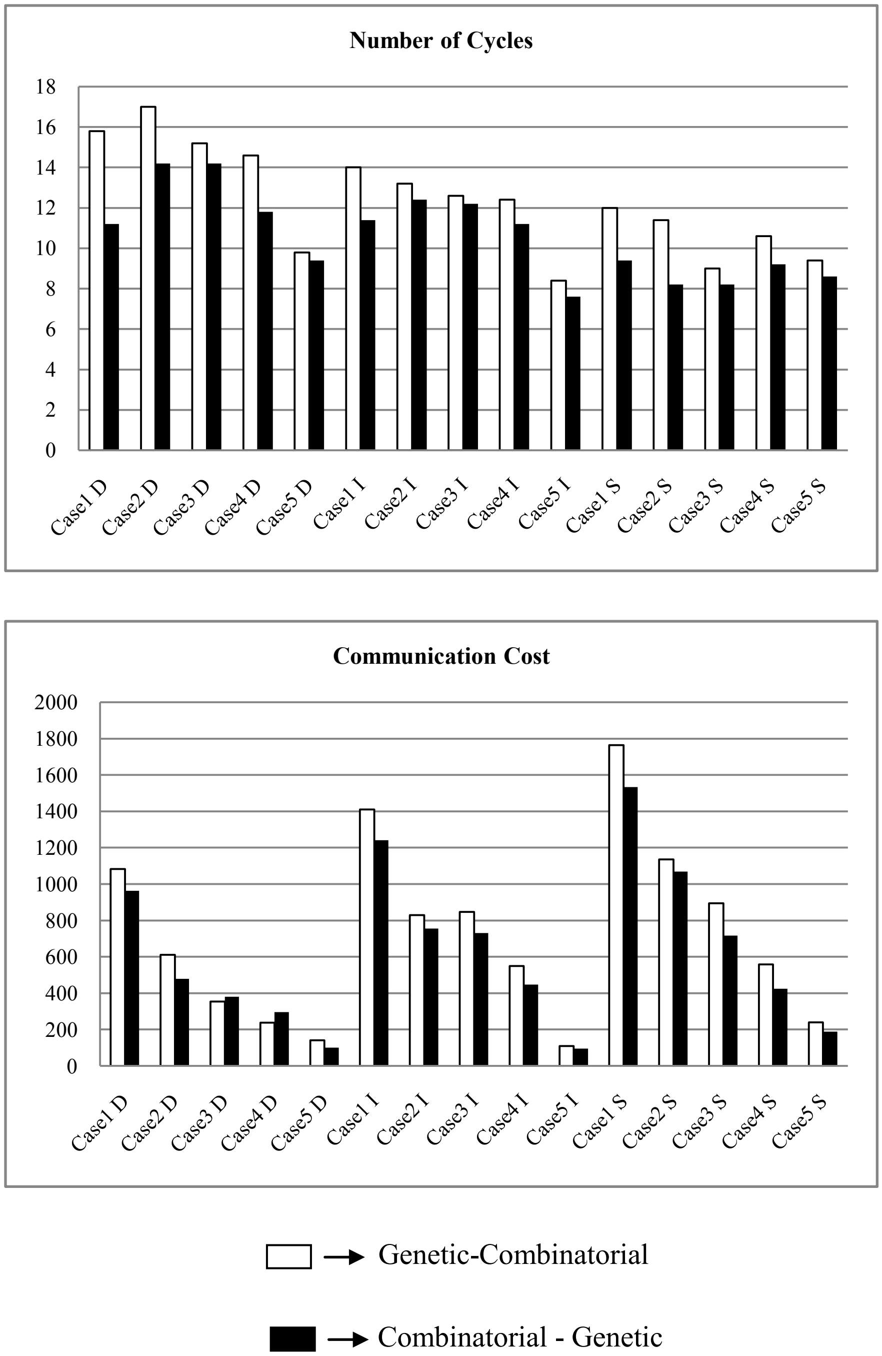
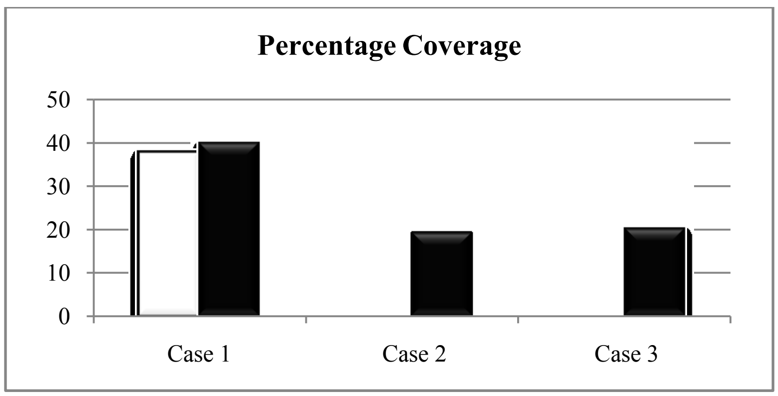
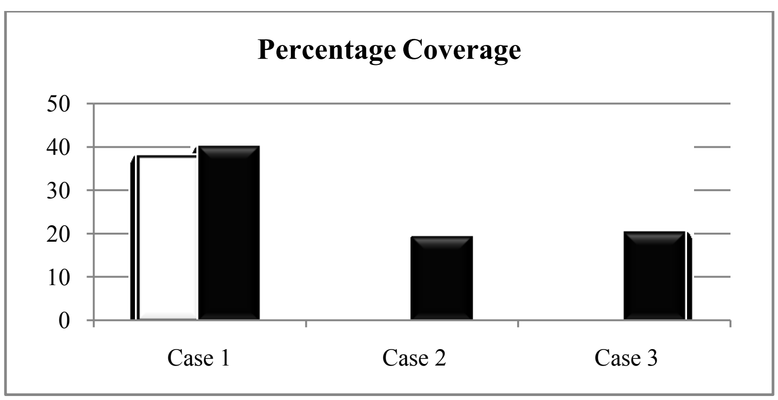
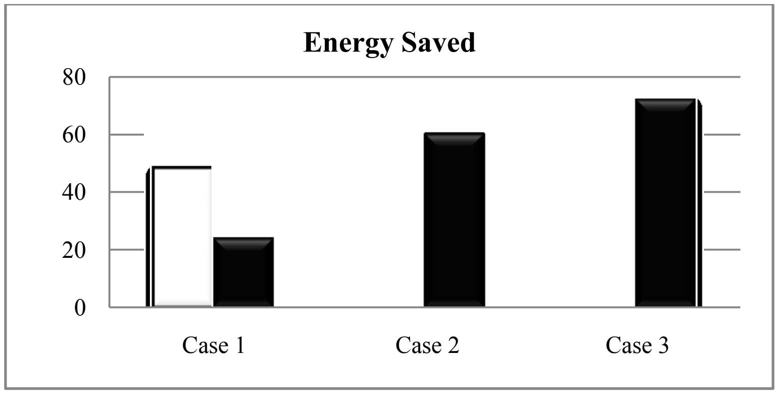


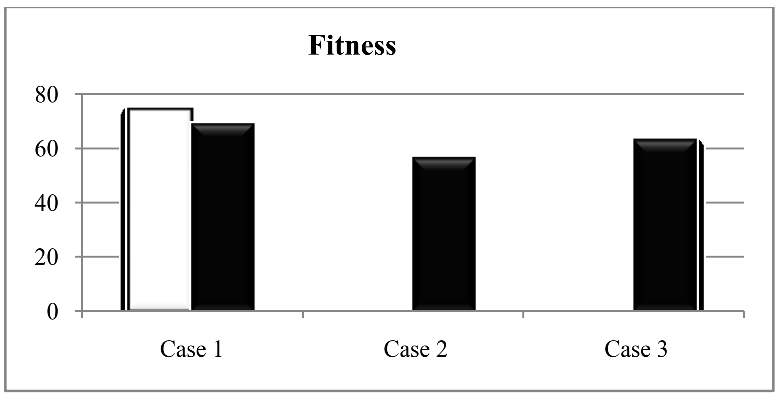
Figure 6.3: Graphs comparing both the sequences.

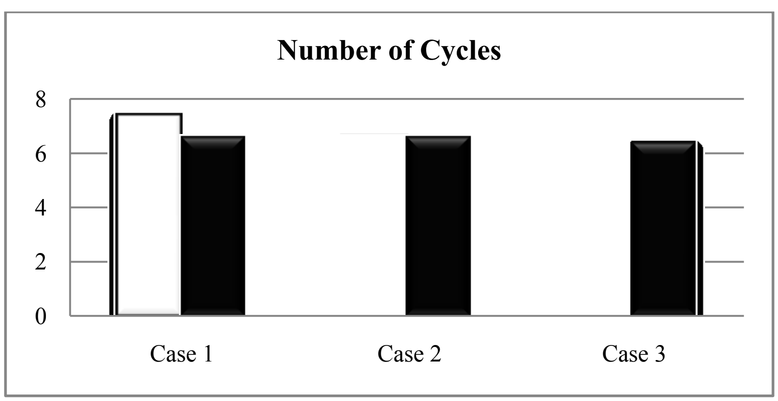
From the graphs it can be seen that both the approaches give a more or less similar output as far as the percentage of coverage, quality of coverage, energy saved and fitness is concerned. However the combinatorial-genetic approach proves to be a better approach when number of cycles that the algorithm takes to come to a stable state is considered, this is because this approach considers the parameter energy saved while determining the starting point in the search space for the genetic algorithm. Also, the combinatorial-genetic approach is more effective when the communication cost is considered as it initially shortlists the cheapest communication links and depending on the desired fitness it has some of the communication links in the selected pool swapped. However, the combinatorial-genetic approach limits the randomness with which the other approach searches. So, in case of extreme conditions where the search space is very large, this is the case in most practical conditions the genetic algorithm – combinatorial algorithm gives better output. Just to illustrate this point we have deployed very few sensors in our existing search area and have compared the results this is illustrated in figure 6.4. In the figure it can be observed that the first approach give better results in fitness and communication costs.






Energy Saved
80
60
40
20
0
Case 1
Case 2
Case 3


Fitness
80
60
40
20
0
Case 1
Case 2
Case 3


Number of Cycles
8
6
4
2
0
Case 1
Case 2
Case 3

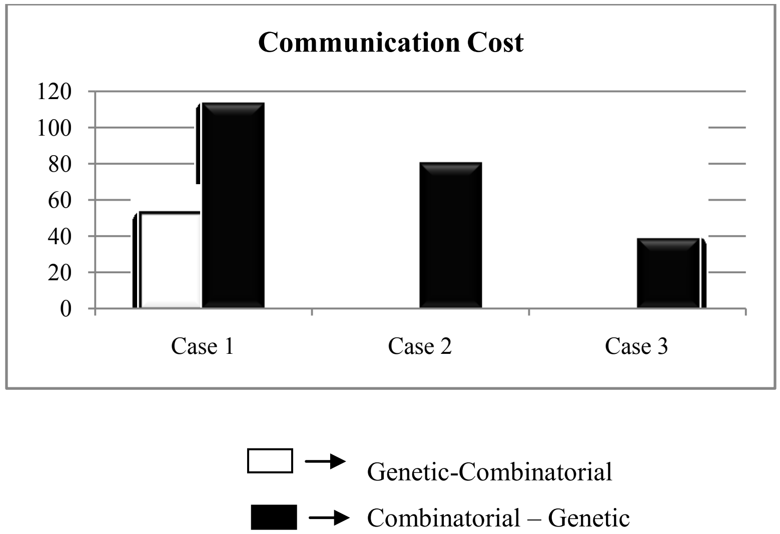


Figure 6.4: Graphs comparing both sequences in extreme conditions

Chapter VII - Conclusion

In our research we have attempted to propose algorithms for the smooth operations of wireless sensor networks; from determining which sensors to be in an active state to how the sensed data should be efficiently reported to the sink nodes. In this first part, we propose a scheme by which we can control the activation/deactivation process in a wireless sensor network while considering multiple optimization parameters. We introduce an evolutionary algorithm that proposes different solutions to the optimization problem and accordingly the fit solution is selected. In order to speed up the process of getting the solution by GA, accelerated GA is introduced. The intelligent mutation and healthy crossover helps in traversing the search space in a more predictable way. Random partial elitism tries to avoid leaving critical parts of the search space unexplored. From the results it can also be observed that with same amount of energy saved, we could get different percentage and quality of coverage depending on the physical parameters like the number of sensors deployed and the size of the area being monitored.

In this second part of our research we propose a novel method to efficiently form a weight based cluster formation algorithm for wireless sensor networks. The network is self-organized such that any resource A while determining which resource B to report to not only considers the physical distance between them but also considers the receiving capacity of all the eligible resources of type B and the physical distance of all other unallocated resources of type A from all the available resources of type B. In this attempt to manage to find an allocation that considering the system as a whole gives energy efficient solutions. The efficiency of the algorithm is tested by comparing it with a robust graph approach, which is a greedy approach for solving the problem. The efficiency of the proposed combinatorial optimization algorithm is better than that of the greedy algorithm in most of the cases; it also avoids the local shortsighted issues that are dealt with while using the greedy approach. One of the disadvantages it has over the robust graph approach is that it takes a longer time to process the best allocation of resources.

In the final part of our work, we have employed both the proposed algorithms to device a method for monitoring a area by heterogeneous WSN. The proposed method helps us determine which particular sensors should be turned on and to which cluster heads should those sensors report to. The desired activity can be executed in two ways either by first determining which sensors to be turned on or by first clustering the network by determining which sensors should report to which other cluster heads. Both the possible sequences are executed and the impact the sequence has on the results are observed. Also, the nature of the results is analyzed and the particular sequence that is suitable for a particular scenario is suggested.

7.1 Future work

Since our research has three major parts, each part could be further extended in different unique ways. The bipartite graph theoretic model can be further modified to a tripartite graph model representing a heterogeneous WSN model. With one set of nodes each for the sensors, cluster heads and region monitored. Different sensor states like active, transmit, and sleep can be introduced. The edges in the graph can be allocated weights to them. With the weight of sensor – cluster head representing the role the sensor is playing. The model can be further improved in various aspects to make it robust enough to handle a variety of different situations.

The multi-stage graph theoretic model can be further be enhanced to deal with redundancy by deciding how many resources can a particular resource report to, this feature is very useful when the area being monitored is of high priority and if due to certain factors, some signals or data is lost it can be retrieved from an alternate source.

The research which analyzes the impact of the sequence of execution can be further extended by making it dynamic. Depending on the physical conditions of the monitored area, the sequence that provides more efficient result should be determined and accordingly the appropriate sequence should be executed.

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